TECHNICAL SPECIFICATION

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Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors —

Part 1:
Fractional efficiency testing with fine particles (0,3 µm to 5 µm optical diameter)

Véhicules routiers — Équipement d'épuration d'air d'entrée pour moteurs à combustion interne et compresseurs —

Partie 1: Contrôle d'efficacité fractionnelle avec particules fines (diamètre optique de 0,3 µm à 5 µm)

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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of document:

- an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

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An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 19713-1 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 7, *Injection equipment and filters for use on road vehicles*.

ISO/TS 19713 consists of the following parts, under the general title *Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors*:

- *Part 1: Fractional efficiency testing with fine particles (0,3 µm to 5 µm optical diameter)*

- *Part 2: Fractional efficiency testing with coarse particles (5 µm to 40 µm optical diameter)*

Introduction

The engine air cleaner/filter fractional efficiency test methods described in this part of ISO/TS 19713 have been developed to cover traditional and new particulate air filters in order to remove airborne contaminants specifically to protect the engine.

Air cleaner fractional efficiency is one of the main air cleaner performance characteristics. This part of ISO/TS 19713 has been established to address the measurement of this parameter. The objective of the procedure is to maintain a uniform test method for evaluating fractional efficiency of air cleaners and air filters on specified laboratory test stands.

The data collected in accordance with this part of ISO/TS 19713 can be used to establish fractional efficiency characteristics for air cleaners and filters tested in this manner. The actual field operating conditions (including contaminants, humidity, temperature, mechanical vibration, flow pulsation, etc.) are difficult to duplicate. However, with the procedure and equipment set forth, comparison of air filter fractional efficiency can be made with a high degree of confidence.

Road vehicles — Inlet air cleaning equipment for internal combustion engines and compressors —

Part 1:
Fractional efficiency testing with fine particles (0,3 µm to 5 µm optical diameter)

1 Scope

This part of ISO/TS 19713 describes laboratory test methods to measure engine air cleaner and filter performance by fractional efficiency tests for particles from 0,3 µm to 5 µm optical diameter.

Performance includes, but is not limited to, airflow restriction or pressure loss, initial and incremental fractional efficiencies during dust loading.

The purpose of this test code is to establish and specify consistent test procedures, conditions, equipment and performance reports in order to enable comparison of filter performances of air cleaners and air filter elements used in engine air induction systems. It specifies the critical characteristics of equipment, test procedure and report format required for the consistent assessment of filter elements in a laboratory test stand.

ISO/TS 19713-2 describes fractional efficiency tests with particles from 5 µm to 40 µm optical diameter.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies

ISO 5011:2000, *Inlet air cleaning equipment for internal combustion engines and compressors — Performance testing*

ISO 12103-1, *Road vehicles — Test dust for filter evaluation — Part 1: Arizona test dust*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
air cleaner assembly
assembly which includes the air cleaner housing and the air filter element

3.1.1
single-stage air cleaner
air cleaner which does not incorporate a separate pre-cleaner

3.1.2
multistage air cleaner

air cleaner consisting of two or more stages, the first usually being a pre-cleaner, followed by one or more filter elements

NOTE If two elements are used, the first is called the primary element and the second is called the secondary element.

3.1.3
pre-cleaner

device usually using inertial or centrifugal means to remove a portion of the test dust before reaching the filter element

3.2
air filter element

actual filter supported and sealed within the air cleaner assembly

3.3
test airflow rate

measure of the volume of air passing through the test duct per unit time

NOTE The test airflow rate is expressed in cubic metres per second.

3.4
pressure loss

permanent pressure reduction due to a decrease in the flow energy (velocity head) caused by the filter (Pa at standard conditions of 20 °C and 101,3 kPa)

3.5
fractional efficiency

$E_{\mathrm{f},i}$

ability of the air filter to remove particles of a specified size expressed as a percentage for particle size i

$$E_{\mathrm{f},i} = \frac{C_{1,i} - C_{2,i}}{C_{1,i}} \times 100 \quad (1)$$

where

$C_{1,i}$ is the number of particles per unit volume of specified size, i, upstream;

$C_{2,i}$ is the number of particles per unit volume of specified size, i, downstream

NOTE Fractional efficiency is expressed in percent.

3.6
fractional efficiency before dust loading

efficiency before the collected particles have any measurable effect on the efficiency of the filter under test

NOTE The collected particles can affect the measured filter efficiency before enough aerosol is collected to have any measurable effect on the filter pressure loss.

3.7
incremental fractional efficiency

efficiency, determined at the specified flow rate as a function of particle size at 10 %, 25 %, 50 % and 100 % of filter life, which is determined by pressure loss across the filter as the filter is loaded with ISO 12103-1 test dust

NOTE 1 The values of filter pressure loss, ΔP_i, at which the incremental fractional efficiencies are measured can be calculated from

$$\Delta P_i = \Delta P_\mathrm{o} + \Delta L_i (\Delta P_\mathrm{d} - \Delta P_\mathrm{o}) \tag{2}$$

where

ΔP_o is the initial pressure loss;

ΔL_i is the fraction of filter life;

ΔP_d is the specified terminal pressure loss.

NOTE 2 If necessary, the requester and the tester can agree upon different criteria for incremental fractional efficiency.

3.8
fractional penetration

$P_{\mathrm{f},i}$

ratio of the concentration of particles of specified size exiting the filter to the concentration of particles of specified size entering the filter expressed in a percentage for particle size i

$$P_{\mathrm{f},i} = 100 - E_{\mathrm{f},i} \tag{3}$$

NOTE Fractional penetration is expressed in percent.

3.9
test dust loading

mass of test dust collected by the air cleaner assembly or air filter element at a specified flow rate expressed in grams

3.10
particle measurement device
aerosol spectrometer

instrument for sizing, or counting, or sizing and counting, aerosol particles

NOTE Recommended particle counters are optical particle counters (OPC) or other counters demonstrating good correlation in measuring particle sizes, e.g. aerodynamic particle counters (APC).

3.11
test aerosol

particles suspended in air, used for filter efficiency evaluation or dust loading

3.11.1
fractional efficiency test aerosol

aerosol used to measure the efficiency of the test filter, the concentration of which is low enough to prevent coincidence-related errors in the particle counters, and does not change the filter efficiency due to loading

NOTE The aerosol charge is reduced so that it approximates a Boltzman equilibrium charge distribution. The requirements for the efficiency challenge aerosol are given in 5.2.10 and 5.2.11.

3.11.2
loading test aerosol

aerosol used to load the filter, the concentration of which is high enough to allow loading of the filter in a reasonable amount of time

NOTE The requirements for the loading test aerosol are given in 5.2.13.2.

3.12
correlation ratio

R

ratio of the number of particles observed at the downstream sampling location to the number of particles at the upstream sampling location when no filter is installed in the test system

NOTE 1 This number can be greater or less than 1.

NOTE 2 The method of calculating the correlation ratio is given in Annex B.

3.13
log mean diameter

$D_{\mathrm{l},i}$

weighted mean diameter calculated by

$$D_{\mathrm{l},i} = \left(D_i \times D_{i+1}\right)^{1/2} \tag{4}$$

where

D_i is the lower threshold of particle size range;

D_{i+1} is the upper threshold of particle size range

3.14
geometric (volume equivalent) diameter

$D_{\mathrm{g},i}$

diameter of a sphere with the same volume as the particle being measured

NOTE For a spherical particle, it is the diameter of the sphere.

3.15
optical (equivalent) diameter

$D_{\mathrm{o},i}$

diameter of a particle of the type used to calibrate an optical sizing instrument that scatters the same amount of light as the particle being measured

NOTE Optical diameter depends on the instrument, the type of particle used to calibrate the instrument (usually polystyrene latex spheres), the optical properties of the particle being measured, and the size of the particle.

3.16
aerodynamic (equivalent) diameter

D_{ae}

diameter of a sphere of density 1 g/cm^3 with the same terminal velocity as the particle being measured, due to gravitational force in calm air

NOTE 1 The aerodynamic diameter will be used to report results to avoid different diameter measures due to different sizing and counting techniques.

NOTE 2 Annex F provides additional information about aerodynamic diameter.

3.17
high efficiency particulate air

HEPA

filter having 99,95 % efficiency at most penetrating particle size (class H13 in accordance with EN 1822), or 99,97 % (or higher) fractional efficiency at 0,3 µm using DOP aerosol as defined by IEST RP-CC001 recommended practice

3.18
neutralization
aerosol whose charge distribution is reduced until it provides a Boltzman equilibrium charge distribution

4 Principle

The primary objective of this test procedure is to enable an assessment of air cleaners for pressure loss and fractional efficiency against standardized laboratory particulate challenges. Because the test methods exclude the full range of possible particulate challenges and environmental effects, the relative ranking of filters may change in service. Note that absolute comparability is only possible with air cleaners of the same shape and size, as well as of the same position in the test duct. In order to get comparable results to the dust loading capacity, gravimetric efficiency and airflow restriction/pressure loss tests, the fractional efficiency test can be done simultaneously. (See ISO 5011.)

5 Test equipment, accuracy and validation

5.1 Measurement accuracy

Accuracy requirements are given in Table E.1.

5.2 Test stand configuration

5.2.1 General

Complete vehicle manufacturer air cleaner assemblies or individual air filter elements may be tested. The test stand shall consist of the following major components and shall be arranged as shown in Figure 2.

NOTE 1 Results can vary depending on configuration.

NOTE 2 Air cleaner assembly orientation will affect performance. It is advisable that air cleaner assemblies be oriented and tested as installed in the vehicle.

Figure 2 shows a set-up to measure the performance of an air cleaner assembly.

Figure 3 shows a recommended air cleaner housing to measure the performance of a panel-type air filter element.

Figure 4 shows a recommended air cleaner housing to measure the performance of a cylindrical-type air filter element.

5.2.2 Unit under test

5.2.2.1 General

The unit under test may be an air cleaner housing with filter element or elements or it may be a housing designed to hold a filter element with appropriate inlet and outlets. The unit under test may be or may include a pre-cleaner. The scope of this test procedure does not include the testing of air cleaner systems without tubular inlet and outlet connections. However, designs such as perforated or louvered inlet systems could be tested with the unit under test inside a plenum that would include a tubular inlet. Non-tubular air cleaner systems outside the scope of this test procedure may still be evaluated as agreed upon between the tester and customer.

5.2.2.2 Air cleaner assembly

Air cleaner assemblies shall be evaluated using the set-up shown in Figure 2.

5.2.2.3 Evaluating panel air filter elements

In general, panel-type air filter elements may be tested using the recommended housing shown in Figure 3.

5.2.2.4 Evaluating cylindrical/round air filter elements

Figure 4 shows a recommended housing to test cylindrical-type air filter elements. This housing design is similar to the one recommended in ISO 5011.

5.2.3 Ducting

Upstream and downstream cylindrical ducting shall be made of conductive material and all components shall be commonly grounded from the aerosol inlet section to the downstream sampling section.

5.2.4 Airflow conditioning

Inlet air shall be conditioned in accordance with the requirements of ISO 5011, i.e. (23 ± 5) °C and (55 ± 15) % relative humidity (RH). The inlet air shall be filtered with a HEPA filter if the background particle concentration exceeds the requirements in 7.7.2.3 and 7.7.4.3.

5.2.5 Test configurations

The upstream and downstream ducting can be constructed vertically (recommended), horizontally, or a combination based on space constraints. The example in this procedure shows a vertical configuration to test both air cleaners and panel-type air filters. The particle samplers are located vertically in each test section, which reduces the probability of particle loss and enables sampling of large particle sizes of interest. The underlying test system design will reduce particle losses and meet the requirements of Tables E.1 and E.2.

5.2.6 Airflow ducting

The test system should be capable of handling user-specified flow rates. Further, the test system will maintain the required flow rates with air cleaner assembly pressure loss up to 10 kPa. Primary duct sizing shall conform to the "nominal" duct diameter and flow ranges in Table 1. Higher and lower flow rates may use duct sizes scaled appropriately.

Table 1 — Duct diameter versus flow range

Nominal duct diameter	Area	Velocity	Flow range low	Flow range high	Reynolds number	
mm	m^2	m/s	m^3/h	m^3/h	at low flow	at high flow
50	0,002 02	11,6	85	425	40 407	202 034
100	0,008 1	5,8	170	850	40 407	202 034
150	0,018 2	5,2	340	1 700	53 876	269 378
200	0,032 4	5,8	680	3 400	80 813	404 067

NOTE A 10 µm particle with a specific gravity of 2 settles at about 6×10^{-3} m/s in still air. At the minimum velocity of approximately 5,1 m/s, this would result in a 10 mm drop in that 10 µm particle over a 3 m run.

5.2.7 Inlet filtration

Test inlet airflow shall be filtered with a HEPA filter to remove the majority of ambient aerosol, if required, in accordance with Annex E.

5.2.8 Flow uniformity

The test system shall be designed to provide uniform and steady airflow to the air cleaner assembly or to the air filter element under test, as stated in the test set-up.

NOTE Uniform airflow is required in sections where isokinetic samplers are located when evaluating air cleaner assemblies. Proper flow distribution will facilitate a representative aerosol sample being drawn by the isokinetic samplers. See 5.2.10.4 for flow uniformity measurements.

5.2.9 Leakage

It is important to minimize leakage into the test system to obtain good data. Depending on where the leakage occurs, it can cause major errors in particle counting.

As a minimum, all connections and joints should be checked for visual leakage using soap bubbles. Any known soap solution can be used for the test. Preferably, the soap solution (foam) will be applied using a brush at all connections and joints. Leaks are especially important on the clean side of the air cleaner. See Annex H for more information.

5.2.10 Fractional efficiency test aerosol generator

5.2.10.1 General

The aerosol generator for fractional efficiency tests shall provide a stable and homogenous aerosol concentration and size distribution. The size distribution of the aerosol shall have sufficient particles for statistical evaluation in each size class, as explained in Clause 7. If high-resolution particle spectrometers are used, size classes may be combined to achieve the required counts using the size ranges in 5.2.13. The total concentration of the aerosol in the test duct shall not exceed the limit of the particle counter, as discussed in 5.2.13.3. The efficiency test aerosol concentration shall be low enough so there is no change in efficiency during the test, as measured by the penetration data acceptance criteria in 7.7.4 (i.e. no loading effects). The size distribution and concentration stability requirements are established by the data quality requirements in Clause 7.

5.2.10.2 Aerosol generation

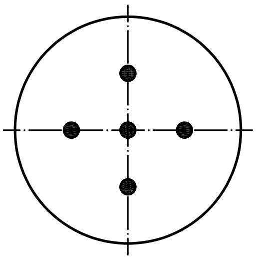
The potassium chloride aerosol generator for fractional efficiency tests shall nebulize a saline solution to produce a homogeneous mist aerosol with stable concentration and size distribution. The droplets shall be dried to form salt particles by using, for example, dry dilution air, heat, or desiccant. The efficiency test aerosol generator shall be capable of dispersing KCl (potassium chloride aerosol) at a concentration low enough to meet coincidence error requirements for the particle counter used. Compressed air used to operate and transport the challenge aerosol should be HEPA filtered and dried before entering the feeding system.

5.2.10.3 Aerosol dispersion

The efficiency test aerosol should be injected against the airflow coming from the inlet HEPA filter(s). Care should be taken to keep the injection velocity low enough to keep the larger particles in the challenge aerosol from impacting on the walls of the inlet aerosol ductwork. The objective is to allow the inlet air to turn the challenge aerosol and result in a more uniform distribution of concentration and particle size distribution across the duct, even before it enters the upstream static mixer.

5.2.10.4 Aerosol uniformity

During validation of uniformity and concentration of the efficiency test aerosol, no air cleaner shall be installed in the location of the test filter (see Figure 2). Instead, a smooth, straight pipe or an elbow may be used. The uniformity of the particle size distribution and the concentration of the test aerosol used for fractional efficiency tests may be verified by use of a particle-sizing instrument that will also be used in the test system. This particle-sizing instrument shall draw samples upstream and downstream of the air cleaner mounting position using the isokinetic samplers. For each test duct the minimum and maximum flow rate will be used for this evaluation (see Table 1). Samples shall be drawn by the isokinetic samplers along a diameter at three locations. For tube diameter D, locations will be 0,15D, 0,5D and 0,85D (see Figure 1). The measurements will be performed in a plane along two perpendicular diameters. A minimum of three samples shall be drawn at each sampling location, and the resulting number distribution shall be averaged. As far as possible, the samples will be taken at random. The average values for each reported particle-size range shall not vary by more than ±10 % for channels less than 5 µm particles among the five locations. This indicates that the efficiency test aerosol is uniformly distributed across the test duct, and that the centreline sample is representative of the overall challenge.



NOTE For tube diameter D, the sampling positions are the following:

- horizontal: 0,15D; 0,5D; 0,85D;
- vertical: 0,15D; 0,85D.

Figure 1 — Location of isokinetic sampling points for validation

5.2.11 Aerosol neutralizer

The efficiency test aerosol shall be neutralized by passing it through a radioactive (minimum 5 mCi) or other ion generating device. The feed aerosol shall be neutralized to approach a Boltzman equilibrium charge distribution.

Generated and dispersed particles often obtain a high level of electrical charge. To obtain comparable results for different aerosols and different generation methods, the aerosol's charge distribution shall be reduced until it provides a Boltzman equilibrium charge distribution. A Boltzman equilibrium charge distribution is the minimum stable charge level and is reached by an aerosol when it is aged. This state of an aerosol cannot be generated artificially in a comparably short time. For many applications, e.g. filter testing, it is sufficient to reduce the charges, utilizing ionized air, to a minimum level. To reach this charge level quickly in a test system the efficiency aerosol is mixed with a high concentration of air ions. To create a high level of air ions, an electrostatic corona (ion blower) or radioactive air ionizer shall be used. The ionizer shall produce a sufficient concentration of bipolar air ions to mix with the aerosol so that the resulting aerosol has a charge distribution that approximates a Boltzman distribution. An aerosol that has Boltzman equilibrium charge distribution is said to be neutralized. The aerosol is not neutral in the sense that all of the particles are neutral, i.e.

- the level of neutralization shall be optimized by methods described in Annex G;
- aerosol may become charged in transport through tubing and test duct, so the neutralization should take place as close as practical to the filter under test;
- a neutralizer is required for fractional-efficiency tests and is optional for dust-holding capacity tests.

5.2.12 Upstream and downstream sample probes

Sampling probes shall be isokinetic (local velocity of duct and probe to be equal) to within ±20 %. The same probe design should be used before and after the filter. Sampling probes shall be located on the centreline of the test duct. Sample probes shall be located at least seven diameters downstream of any bends, reducers, expanders, etc. The sampling probe shall be at least four diameters upstream of any bends, reducers, expanders, etc. The samplers will also be located in the centre of the duct. The probes shall be made of electrically conductive metallic tubing with a smooth inside surface. The design of the probes and sampling lines will reduce particle losses. The inlet of the sampling probes shall be sharp edged and shall be located near the centre of the duct. Both the upstream/downstream sampling lines should be identical, straight (or no more than one bend) and as short as possible. See Annex I for details on isokinetic sampling. A short ($\leqslant$ 50 mm) flexible connection to the particle counter may be used to allow some flexibility and reduce stress on the counter inlet. PTFE may not be used as flexible tubing. Use conductive tubing (e.g. plasticized PVC) instead. For more information on tubing, see the Bibliography.

Sampling probe ducting to the particle counter must be set up in a way that no sedimentation of large particles takes place, i.e.

- vertical orientation of the tubing;
- sufficient flow velocity;
- short connection length between particle counter and sampling probe;
- avoidance of bends in the tubing;
- no sharp angles if bends are necessary.

5.2.13 Loading test aerosol generator (see ISO 5011)

5.2.13.1 General

Loading aerosol generation shall be in accordance with ISO 5011:2000, 6.2.1 to 6.2.4.

5.2.13.2 Loading test aerosol (air cleaner assembly only)

A dust injector (see ISO 5011:2000, Figure B.2 or B.3) shall be used to disperse the loading test aerosol (ISO 12103-1 A2 test dust). The dust feeder location is shown in Figure 2. Test dust shall be injected downstream from the upstream sample probe in order to reduce upstream optics contamination problems. The injector nozzle shall extend into the duct so that dust is injected at a point beyond the adjacent sample probe. The nozzle will extend into the duct to the entrance of the piezometer tube. The inside diameter of the extension tube will be the same as the outside diameter of the injector nozzle. A slight offset (but close to the centre as possible) of either the probe or the injector extension, or both, may be required so they can extend past each other inside the duct elbow. The extension nozzle shall be centred in the duct.

5.2.13.3 Loading test aerosol dust feeder

A dust feeder capable of feeding a stable (within ±5 %) concentration of 1g/m^3 of air at the test flow rate shall be used. Reference the dust feeder specifications and validation procedure in ISO 5011.

5.2.14 Upstream and downstream particle counters

5.2.14.1 General

Upstream and downstream particle counters shall be of the same model and shall be matched as closely as possible. A single particle counter can also be used for efficiency measurements using sequential measurements alternately sampling upstream and downstream. The use of a single particle counter sampling downstream only is not allowed. The airborne particle counters shall be capable of counting particles in the 0,3 µm to 5 µm optical size range and 0,5 µm to 10,0 µm aerodynamic size range. It is also desirable for the particle counters to have a design incorporating clean sheath air to protect and keep the optics clean. The particle counters may also need to be adapted with an exhaust port that can be routed back to the test system vacuum. Without this exhaust set up, the particle counters may not be able to perform at the rated flow. Counters must be calibrated using NIST traceable PSL (polystyrene latex) spheres (see calibration procedure in ASTM F328). Correlation shall be done in accordance with Clauses 6 and 7 with an elbow, or a tube, or an elbow and tube the same size as the test ducting in place of the air cleaner assembly. The inlet/outlet duct orientation shall be maintained during correlation measurements and testing. Data should also be reported in equivalent aerodynamic size ranges. Most laboratories currently use optical particle counters, however, the technical advantages of using aerodynamic particle counters is also well recognized. The particle counter shall be able, at a minimum, to discriminate eight logarithmically spaced particle size classes.

There is a finite measurable delay for particle transport from the upstream sample probe to the downstream sample probe. It is possible to improve data quality by starting the downstream sample count after a delay equal to the transport time between the sample probes. The transport time can be measured or calculated.

5.2.14.2 Particle counter calibration

The particle counters shall be calibrated with polystyrene latex particles of appropriate size prior to system start-up and a minimum of once a year to verify that the size calibration has not changed. It is recommended that the particle counter calibration be verified periodically during the year between calibrations. If the counter shows an unacceptable change in the calibration, the counter should be serviced.

5.2.14.3 Particle counter zero

The particle counters will be checked using a cartridge filter on the inlet (> 99,99 % efficient at 0,12 µm). The particle counter shall count ten particles or less per minute per channel.

5.2.14.4 Maximum particle concentration

The maximum total particle concentration shall be established to prevent coincidence counting (i.e. counting more than one particle at a time). A recommended method for establishing this limit is to conduct filter efficiency tests at a series of different concentrations and compare the results. The maximum concentration is determined at the point where increasing the concentration by a factor of two causes the fractional efficiency in the smallest size range at the higher concentration to be more than 5 % less than the fractional efficiency at the lower concentration. Another method is to increase the concentration in steps (e.g. by using a diluted and an undiluted aerosol) and determine the concentration where the particle counter starts showing significant deviation from the expected concentration in the smallest size range. An example is given in Annex D.

5.2.14.5 Particle counter flow

The particle counter flow rate shall remain constant within ±5 % for the duration of a test including the correlation done before the test.

5.2.14.6 Upstream/downstream particle counter correlation ratios

Correlation shall be performed using an elbow, or a tube, or an elbow and tube, the same size as the test ducting in place of the air cleaner assembly and in the same orientation as the air cleaner assembly inlet/outlet tubes under test. See 7.6 to calculate correlation ratios.

5.2.15 Inlet and outlet piezometer tubes

Inlet and outlet piezometer tubes shall be installed upstream and downstream of the air cleaner unit under test. Inlet and outlet transition tubes shall adapt the unit under test to the piezometers if they are a different size from the piezometer. The inlet and outlet piezometer tubes shall be designed as specified in ISO 5011.

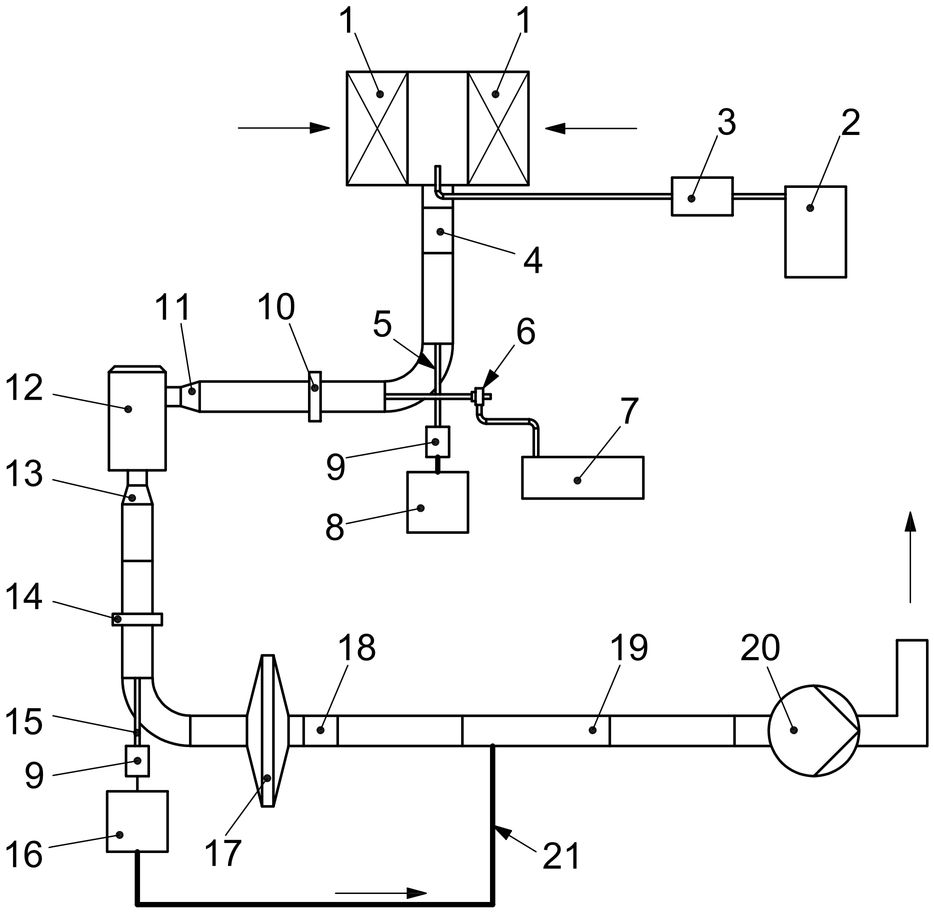
5.2.16 Airflow measurement

Measure airflow with accuracy in accordance with Annex E. Convert all volume flow rates to actual conditions at the inlet of the device under test.

5.2.17 High efficiency test and purge time measurement

As part of system set-up and validation, conduct an initial efficiency test using a HEPA or ultra low particulate air (ULPA) filter as the filter under test. The standard fractional efficiency test as described in Clause 6 should be followed. The fractional efficiency in all size ranges should be greater than 99,9 %.

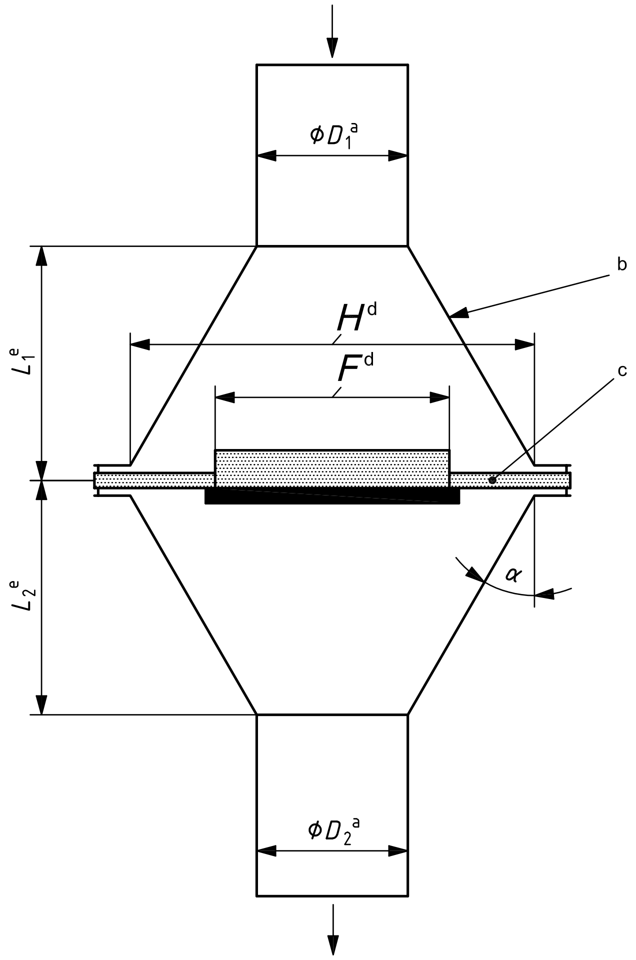
These measurements can be used to establish the minimum purge times when switching from upstream to downstream sampling with sequential sampling systems. If the purge time is too short, the downstream count will include residual particles from the upstream sample causing the measured efficiency to be low.



Key

1	HEPA inlet air filter
2	challenge aerosol feeder
3	aerosol neutralizer
4	static mixer
5	upstream isokinetic sample probe
6	dust injector
7	loading dust feeder
8	upstream particle counter
9	dilution (if required)
10	inlet piezometer tube
11	inlet transition tube (if required)
12	unit under test
13	outlet transition tube (if required)
14	outlet piezometer tube
15	downstream isokinetic sample probe
16	downstream particle counter
17	absolute filter
18	airflow straightener
19	airflow meter
20	airflow pump (exhauster)
21	particle counter exhaust port

Figure 2 — Test set-up to evaluate air cleaner assembly



Key

D_1, D_2	tube diameters
F	cross-sectional area of the panel filter element paper pack
H	cross-sectional area of the housing
L_1, L_2	length of air cleaner housing
α	angle $\leqslant$ 30° around the perimeter of the diffuser

[a] $D_1 = D_2$ and depends on the test flow rate (see Table 1).

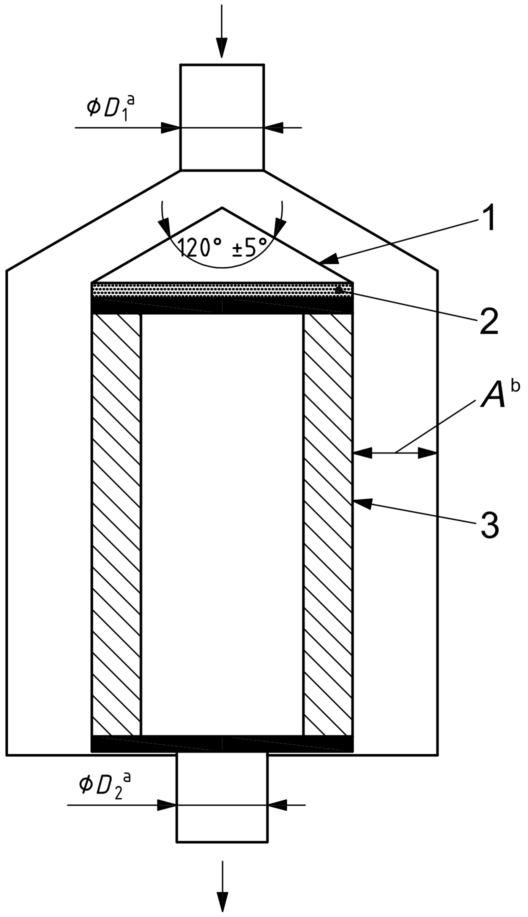
[b] Smooth transition from a round duct to a rectangular cross-section.

[c] Filter should be sealed to the plate, for example see ISO 5011.

[d] Ratio of H to F shall not be less than 0,5.

[e] $L_1 = L_2$ and depends on area H and included angle α.

Figure 3 — Test set-up for panel-type and axial flow cylindrical-type air filter elements



Key

D_1, D_2	tube diameters
A	area
1	diffuser plate/cone
2	sealing plate
3	cylindrical round conical tapered air filter

[a] $D_1 = D_2$ and depends on the test flow rate (see Table 1).

[b] Area A is adjusted so that the annular face velocity of entry is in the range of (900 ± 50) m/min.

Figure 4 — Test set-up for cylindrical radial flow-type air filter elements

5.3 Test conditions

5.3.1 General

All tests shall be conducted with air entering the air cleaner assembly or air filter element in accordance with 5.2.4, with the permissible humidity variation throughout one single test being ±2 %.

5.3.2 Test aerosol

5.3.2.1 Fractional test aerosol

For this part of ISO/TS 19713, the KCl (potassium chloride) test aerosol shall be used.

5.3.2.2 Loading test aerosol

For this part of ISO/TS 19713, the following test dust shall be used:

- for single-stage air cleaner assemblies and air filter elements: ISO 12103-1 A2 test dust;
- for pre-cleaners and multistage air cleaner assemblies: ISO 12103-1 A4 test dust.

5.3.3 HEPA filter

A HEPA filter is used to provide clean air to the test stand. Limits on the maximum acceptable background counts are given in 7.7.2.3 and 7.7.4.3. A high efficiency filter may be used downstream to protect the flow meter and air moving devices.

5.4 Validation

Prior to initial use, the test stand shall be validated in accordance with Table E.2

IMPORTANT — If the test set-up undergoes any hardware/component changes, it needs to be re-verified and re-evaluated for that portion of the test stand and for those changes.

The validation certifying the performance of a system in accordance with this part of ISO/TS 19713 shall be documented, including the following:

a) system diagram and detailed description, including particle generator used:
   - particle materials used in the tests, including tractability;
   - manufacturer and model of the particle counters;
   - calibration data for the particle counter(s);
   - calibration data for flow measuring device;
   - manufacturer, model number and date of manufacture for the neutralizer system used;

b) calibration data for pressure loss;

c) system performance on flow uniformity;

d) system performance on particle concentration uniformity;

e) data demonstrating that the coincidence counting error meets the criteria of Table E.2;

f) data demonstrating the performance of the neutralizer as described in Annex G;

g) data showing the agreement between upstream and downstream particle counters for a single or dual-counter system;

h) data showing that the efficiency test aerosol concentration is low enough to avoid loading effects during the fractional efficiency before dust loading test;

i) sample test data;

j) sample test data showing the repeatability of test results.

5.5 Reference air cleaner assemblies/air filter elements

Upon initial calibration and validation of the system, the fractional efficiency before dust loading of reference air cleaner assemblies should be measured. These air cleaner assemblies become references that will be used to monitor changes in the test system and will be used for periodic checks of system performance.

5.6 Routine operating procedure

5.6.1 General

See Table E.3.

5.6.2 Periodical start-up procedure

Periodically, as required to maintain accuracy in accordance with Annex E, certain start-up procedures shall be performed to verify the continued proper operation of the test system. Such procedures include but are not limited to:

- verification of particle counter operation such as flow rate and zero count (Table E.3);
- measurement of background particle count in the test duct with no test filter and no test aerosol;
- correlation of upstream and downstream particle sampling and counting systems;
- check zero on pressure measurement devices.

See, for example, Table E.3. The reference air cleaner assemblies or air filters will be used for periodic checks of system performance.

5.6.3 Other periodic procedures

See Table E.3.

6 Fractional efficiency test

6.1 General

The purpose of this test is to determine the particle collection capabilities of the filter. The fractional efficiency test is conducted with constant airflow rate using the aerosol described in 5.2.10.

The filter efficiency test procedure can be done with a pair of particle counters that are used to sample the upstream and downstream flow nearly simultaneously. One particle counter that is used to alternately sample the airflow upstream and downstream may also be used. In the case of a single particle counter, the upstream counts that occur during the time the downstream sample is taken are estimated from upstream counts taken before and after the downstream count. The upstream counts shall be taken as soon before and after the downstream count as possible while allowing for appropriate purge time between upstream and downstream sample periods. Estimating the upstream counts from measurements that are not taken during the test is not allowed. Estimating the upstream counts from measurements with a different sizing method is not allowed.

The calculations shown in this clause are for single counter, sequential sampling systems. Calculations for dual counter systems are the same except that the observed upstream counts are used rather than estimated upstream counts. The data quality requirements for single and dual particle counter systems are identical.

All appropriate validation procedures, system checks, correlations, and reference filter tests as described in Annex E should be done prior to starting a test.

For air cleaner tests as shown in Figure 2, correlations and pressure loss tare measurements are done with a “blank duct” replacing the air cleaner to be tested. The blank duct should be smooth, conductive metal tubing that includes the minimum bends and area changes required to replace the air cleaner housing and connect the inlet and outlet piezometers in the same positions as when the air cleaner to be tested is installed.

For filter element tests using one of the housings shown in Figures 3 and 4, correlations and pressure loss tare measurements are done with the housing to be used during the test installed but no filter element.

Fractional efficiency measurements shall be performed at intervals during the dust-loading procedure to establish a curve of efficiency as a function of dust loading. Efficiency measurements shall be made at the following points during the dust-loading procedure:

a) before any dust is fed to the device;

b) after the dust loading has caused a pressure loss increase of 10 %, 25 % and 50 % of the difference between the beginning and the prescribed end point limit of pressure loss;

c) after dust loading the device to its prescribed end point pressure loss limit.

6.2 Test procedure

a) Temperature, relative humidity and barometric pressure are recorded at the beginning and end of each test. The temperature and relative humidity are monitored continuously throughout the test to ensure that the stability requirements in 5.3 are met.

b) Install the blank duct or element housing in accordance with Figure 3 or 4 in the test system in place of the air cleaner. Set the specified volume flow rate and measure and record the tare pressure loss, background counts and correlation ratios. See Clause 7 for sampling sequence, number of samples required, calculations, and for criteria for accepting data.

c) Mount the air cleaner assembly or air filter element in their respective test housing in accordance with Figure 2, 3 or 4. Test air cleaner assemblies should be mounted in the same orientation as when installed in the vehicle.

d) Set the specified volume airflow rate. The volume flow rate shall be maintained at the specified value ±2 % throughout the test.

e) Condition the air cleaner assembly or the air filter element by stabilizing to temperature and humidity test conditions in accordance with 5.3 at rated flow for at least 15 min.

f) Measure and record the pressure loss (ΔP_i).

g) Measure fractional efficiency before loading. See Clause 7 for sampling sequence, number of samples required, calculations, and for criteria for accepting data.

h) If fractional efficiency before dust loading tests will be followed by a loading test, then begin that test immediately upon completion of the fractional efficiency before dust loading test. Do not interrupt the airflow through the filter under test until the entire test is completed, as this can alter the performance of the filter.

i) Start to feed the ISO 12103-1 A2 test dust.

NOTE The particle counters need to be protected from the high concentrations of ISO 12103-1 A2 fine test dust that are present during filter loading.

Load the filter with ISO 12103-1 A2 test dust until the pressure loss across the filter has increased to the first increment as calculated in 3.7.

j) Stop the loading test aerosol generator.

NOTE Provisions to protect the particle counters from the high concentrations of ISO 12103-1 A2 fine test dust that are present during filter loading need to be removed. It is also important to clean the isokinetic samplers before taking efficiency measurements: this is because during dust loading the samplers can become contaminated. Generally, the samplers can be back flushed with clean compressed air.

k) Measure background/shedding in accordance with 7.7.3.

l) Start the efficiency test aerosol. Allow the upstream and downstream aerosol concentration to stabilize. Measure fractional efficiency. See Clause 7 for sampling sequence, number of samples required, calculations, and for criteria for accepting data.

m) Stop the efficiency test aerosol.

n) Repeat steps i) to m) until the final pressure loss has been reached and the final fractional efficiency has been measured.

o) Measure and record temperature, relative humidity and barometric pressure.

7 Calculations and data acceptance criteria

7.1 General

The calculations and data quality requirements in this clause are performed separately for each of the particle sizing ranges.

The symbols and subscripts in 7.2.1 and 7.2.2 are used in equations in this clause.

7.2 Symbols and subscripts

7.2.1 Symbols

U	upstream counts of each size range (or channel)
D	downstream counts of each size range (or channel)
R	correlation ratio
P	penetration
P'	penetration calculated using Poisson statistics
E	efficiency
T	sampling time
δ	standard deviation of a sample
n	number of sample sets
t	distribution variable

7.2.2 Subscripts

i	sample number
o	observed
c	correlation
b	background
t	testing an air cleaner
u	upstream
d	downstream
e	estimated
lcl	lower confidence limit
ucl	upper confidence limit
n	number of sample sets

NOTE Over bar is used to denote averages, e.g. $\overline{P}$.

7.3 Test sequence

Table 2 includes an example of the test sequence. The sampling sequence within each efficiency measurement for single counter systems is given in Table 3 and the sampling sequence for each efficiency measurement for dual counter systems is given in Table 4. The sampling pattern in Table 3 illustrates one iteration of a sequential upstream-downstream sampling sequence. Sample counts in each size range shall be handled the same way, and this pattern shall be followed for all fractional efficiency tests. An initial upstream sample shall be followed by an upstream to downstream purge. Development of purge times is detailed in 5.2.17. The first downstream sampling shall be followed by a downstream to upstream purge and then shall be followed by another upstream sample. The last four time periods shall be repeated for as many sample sets as are required.

Table 2 — Test sequence

No.	Test procedure step[a]	Characteristic tested	Device in test position	Fractional efficiency aerosol generator	Loading aerosol generator	Counters sampling, or protected
1	b)	Pressure loss tare	Blank duct or empty housing	Off	Off	Off, protected
2	b)	Background	Blank duct or empty housing	Off	Off	On
3	b)	Correlation	Blank duct or empty housing	Off	Off	On
4	b)	Background	Blank duct or empty housing	Off	Off	On
5	c) to f)	Pressure loss	Housing with filter element	Off	Off	—
6	g)	Background	Housing with filter element	Off	Off	On
7	g)	Efficiency	Housing with filter element	On	Off	On
8	g)	Background	Housing with filter element	Off	Off	On
9	—	—	Housing with filter element	Off	Off	Protected
10	i)	Loading	Housing with filter element	Off	On	Off, protected
11	—	—	Housing with filter element	Off	Off	Unprotected and flush
12	k)	Background	Housing with filter element	Off	Off	On
13	l)	Efficiency	Housing with filter element	On	Off	On
14	m)	Background	Housing with filter element	Off	Off	On
Repeat test sequence numbers 9 to 14 until final pressure loss is reached and efficiency at final pressure drop has been measured.						

[a] As specified in 6.2.

Table 3 — Sampling sequence for single counter, sequential sampling systems

Sampling step	Particle counting	Purging
0	No	For first upstream sample
1	Upstream	No
2	No	Upstream to downstream purge
3	Downstream	No
4	No	Downstream to upstream purge
5	Upstream	No
Repeat sampling steps 2 to 5 until a minimum of four upstream samples and three downstream samples have been taken. More repetitions may be required to meet the data quality requirements. Final upstream count not required when measuring background.		

Table 4 — Sampling sequence for dual counter, simultaneous sampling systems

Sampling step	Particle counting	Purging
0	No	For first sample
1	Upstream and downstream	No
2	Upstream and downstream	No
3	Upstream and downstream	No
Take additional samples as needed to meet data quality requirements.		

7.4 Correlation ratio

7.4.1 The correlation ratio R shall be used to correct for any bias between the upstream and downstream sampling systems and counters. The correlation ratio shall be established from the ratio of downstream to upstream particle counts with a blank duct for air cleaner tests or with an empty housing for element tests installed in the test system and before testing an air cleaner or element. The correlation ratio measurement shall be performed at the airflow rate of the air cleaner fractional efficiency test. The general calculation for the correlation ratio, R, as used in this part of ISO/TS 19713, shall be the downstream particle concentration divided by the upstream particle concentration, with the fractional efficiency test aerosol generator on, but without a test device in place.

7.4.2 Background counts shall be made before generating test aerosols. Upstream and downstream sampling shall be done sequentially, starting with an upstream sample, $U_{1,\mathrm{o},\mathrm{b}}$, followed by a downstream sample, $D_{1,\mathrm{o},\mathrm{b}}$, alternating back and forth.

NOTE The procedure is written for single counter, sequential test systems. Dual counter procedures are the same except the upstream and downstream sampling are done simultaneously.

The total number of samples and sampling times shall be determined by the data quality requirements in 7.7.2, except that the final upstream sample is not needed for background sampling. Sampling times upstream and downstream shall be the same for this test.

7.4.3 Start generating aerosol when background counts are complete. Begin sampling after stabilization of the test aerosol, starting with an upstream sample, $U_{1,\mathrm{o},\mathrm{c}}$, followed by a downstream sample, $D_{1,\mathrm{o},\mathrm{c}}$. An additional upstream sample, $U_{(n+1),\mathrm{o},\mathrm{c}}$, shall be made following the last downstream sample, $D_{(n+1),\mathrm{o},\mathrm{c}}$. The total number of samples and sampling times shall be determined by the data quality requirements in 7.7.2. Sampling times upstream and downstream shall be the same for this test.

7.4.4 Aerosol generation shall be turned off and background sampling shall be repeated after completion of the required correlation sampling sets.

7.4.5 The correlation ratio shall then be calculated in accordance with 7.7.1.

7.5 Penetration/fractional efficiency

7.5.1 For the purposes of this part of ISO/TS 19713, penetration, P, shall be the fraction of particles that pass through the air cleaner, and the general calculation for penetration shall be the downstream particle concentration divided by the upstream particle concentration, with the fractional efficiency test aerosol generator on and the test device in place.

7.5.2 Background counts shall be made before generating test aerosols. Upstream and downstream sampling shall be done sequentially, starting with an upstream sample, $U_{1,\mathrm{o},\mathrm{b}}$, followed by a downstream sample, $D_{1,\mathrm{o},\mathrm{b}}$, alternating back and forth. The total number of samples and sample times shall be determined by the data quality requirements in 7.7.4, except that the final upstream sample is not needed for background sampling. A difference between upstream sampling time, T_{u}, and downstream sampling time, T_{d}, is allowable.

7.5.3 Start generating aerosol when background counts are complete. Start sampling with an upstream sample, $U_{1,\text{o,t}}$, followed by a downstream sample, $D_{1,\text{o,t}}$, after stabilization of the test aerosol. Take an additional upstream sample, $U_{(n+1),\text{o,t}}$, following the last downstream sample, $D_{n,\text{o,t}}$. Sampling times T_{u} and T_{d} shall be the same as those used for background sampling.

7.5.4 Aerosol generation shall be turned off and background sampling shall be repeated after completion of the required penetration sampling sets.

7.5.5 Air cleaner penetration shall then be calculated in accordance with 7.7.3.

7.6 Efficiency

7.6.1 In this part of ISO/TS 19713, the general calculation for fractional efficiency, E, shall be ($E = 1 - P$), where penetration P equates to the downstream particle concentration divided by the upstream particle concentration, with the fractional efficiency test aerosol generator on and the test device in place (see 7.5.1).

7.6.2 Air cleaner efficiency shall be calculated in accordance with 7.7.5.

7.7 Data reduction

7.7.1 Correlation ratio data reduction

7.7.1.1 The upstream counts from two samples shall be averaged to obtain an estimate of the upstream counts that would have occurred at the same time as the downstream counts were taken, as shown in Equation (5):

$$U_{i,\text{e,c}} = \frac{U_{i,\text{o,c}} + U_{(i+1),\text{o,c}}}{2} \tag{5}$$

7.7.1.2 The background counts before and after the correlation aerosol test generation shall be simply averaged, as shown in Equations (6) and (7):

$$\bar{U}_{\text{b}} = \frac{\sum\limits_{i=1 \to n} U_{i,\text{o,b}}}{n} \tag{6}$$

$$\bar{D}_{\text{b}} = \frac{\sum\limits_{i=1 \to n} D_{i,\text{o,b}}}{n} \tag{7}$$

7.7.1.3 The correlation ratio shall be calculated for each upstream and downstream sample set using the observed downstream count, the estimated upstream count, the average downstream background count, and the average upstream background count, as shown in Equation (8):

$$R_i = \frac{D_{i,\text{o,c}} - \bar{D}_{\text{b}}}{U_{i,\text{e,c}} - \bar{U}_{\text{d}}} \tag{8}$$

7.7.1.4 These correlation ratios shall be averaged to determine a final correlation ratio value, as shown in Equation (9):

$$\bar{R} = \frac{\sum\limits_{i=1 \to n} R_i}{n} \tag{9}$$

7.7.1.5 The standard deviation of the correlation ratio shall be determined as shown in Equation (10):

$$\delta_\mathrm{c} = \sqrt{\frac{\sum_{i=1\to n} (R_i - \bar{R})^2}{n-1}} \tag{10}$$

7.7.1.6 The standard deviation of the background counts shall be determined as shown in Equations (11) and (12):

$$\delta_\mathrm{u,b} = \sqrt{\frac{\sum_{i=1\to n} (U_{i,\mathrm{o,b}} - \bar{U}_\mathrm{b})^2}{n-1}} \tag{11}$$

$$\delta_\mathrm{d,b} = \sqrt{\frac{\sum_{i=1\to n} (D_{i,\mathrm{o,b}} - \bar{D}_\mathrm{b})^2}{n-1}} \tag{12}$$

7.7.1.7 The 95 % confidence limits of the correlation value shall be determined as shown in Equations (13) and (14):

$$\bar{R}_\mathrm{lcl} = \bar{R} - \left(\delta_\mathrm{c} \times \frac{t}{\sqrt{n}} \right) \tag{13}$$

$$\bar{R}_\mathrm{ucl} = \bar{R} + \left(\delta_\mathrm{c} \times \frac{t}{\sqrt{n}} \right) \tag{14}$$

using the distribution variable, t, specified in Table 5 for a given number of samples, n.

Table 5 — t distribution variable

Number of samples n	Degrees of freedom $v = n - 1$	Distribution variable t
3	2	4,303
4	3	3,182
5	4	2,776
6	5	2,571
7	6	2,447
8	7	2,365
9	8	2,306
10	9	2,262
11	10	2,228
12	11	2,201
13	12	2,179
14	13	2,160
15	14	2,145
16	15	2,131
17	16	2,120

Table 5 (*continued*)

Number of samples n	Degrees of freedom $v = n - 1$	Distribution variable t
18	17	2,110
19	18	2,101
20	19	2,093
21	20	2,086
22	21	2,080
23	22	2,074
24	23	2,069
25	24	2,064
26	25	2,060
27	26	2,056
28	27	2,052
29	28	2,048
30	29	2,045
inf.	inf.	1,960
NOTE See Reference [17].		

7.7.1.8 The 95 % upper confidence limits of the background counts shall be determined as shown in Equations (15) and (16):

$$\bar{U}_{\mathrm{b,ucl}} = \bar{U}_{\mathrm{b}} + \left(\delta_{\mathrm{c}} \times \frac{t}{\sqrt{n}} \right) \tag{15}$$

$$\bar{D}_{\mathrm{b,ucl}} = \bar{D}_{\mathrm{b}} + \left(\delta_{\mathrm{c}} \times \frac{t}{\sqrt{n}} \right) \tag{16}$$

using the distribution variable, t, specified in Table 5 for a given number of samples, n.

7.7.2 Correlation ratio data acceptance criteria

7.7.2.1 Correlation ratio error limit

The number of correlation sample runs, n, shall be at least three and sufficient to satisfy the conditions shown in Equations (17) and (18).

For particle size ranges 0,5 µm to 3 µm:

$$\left(\delta_{\mathrm{c}} \times \frac{t}{\sqrt{n}} \right) \leqslant 0{,}05 \tag{17}$$

For particle size ranges 3 µm to 5 µm:

$$\left(\delta_{\mathrm{c}} \times \frac{t}{\sqrt{n}} \right) \leqslant 0{,}10 \tag{18}$$

This requirement shall be satisfied by calculating this expression after each sample set and halting the testing sequence when the requirement is reached for each size range, or by an acceptance criterion for a predetermined number of sample sets.

7.7.2.2 Limits on magnitude of correlation ratio

The correlation ratio shall meet the requirements specified in Table 6.

Table 6 — Limits on magnitude of correlation ratio

Size range µm	Limits on correlation ratio
0,3 to 1,0	0,90 to 1,10
1,0 to 3,0	0,80 to 1,20
3,0 to 5,0	0,70 to 1,30

7.7.2.3 Correlation ratio maximum background counts

The 95 % upper confidence limit of the upstream and downstream background counts shall be less than 5 % of the average estimated upstream count when the particle generation is as shown in Equation (19):

$$\bar{D}_{\mathrm{b,ucl}},\bar{U}_{\mathrm{b,ucl}} < \frac{\sum\limits_{i=1\to n} U_{i,\mathrm{e,c}}}{n\times 20} \tag{19}$$

7.7.2.4 Correlation ratio minimum average upstream counts

The sum of the estimated upstream counts shall be ⩾ 500 [see Equation (20)]. If a sufficient number of counts is not obtained, the sample time or aerosol concentration shall be increased. The aerosol concentration shall not exceed the concentration limit of the particle counter(s), as determined by 5.2.14.4 and Annex D.

$$\sum_{i=1\to n} U_{i,\mathrm{e,c}} \geqslant 500 \tag{20}$$

7.7.3 Penetration data reduction

7.7.3.1 The upstream counts from the first two samples shall be averaged to obtain an estimate of the upstream counts that would have occurred at the same time as the downstream counts were taken, as shown in Equation (21):

$$U_{i,\mathrm{e,t}} = \frac{U_{i,\mathrm{o,t}} + U_{(i+1),\mathrm{o,t}}}{2} \tag{21}$$

7.7.3.2 The background counts before and after the penetration test shall be simply averaged, as shown in Equations (22) and (23):

$$\bar{U}_{\mathrm{b}} = \frac{\sum\limits_{i=1\to n} U_{i,\mathrm{o,b}}}{n} \tag{22}$$

$$D_{\mathrm{b}} = \frac{\sum\limits_{i=1\to n} D_{i,\mathrm{o,b}}}{n} \tag{23}$$

7.7.3.3 The observed penetration shall be calculated for each upstream and downstream set using the observed downstream count, the upstream count, the average downstream background count, the average upstream background count, the upstream sampling time and the downstream sampling time, as shown in Equations (24) and (25).

If $\bar{D}_{\text{b,ucl}} \leqslant 0{,}05 \times \frac{\sum\limits_{i=1 \rightarrow n} U_{i,\text{o,u}}}{n} \times \left(\frac{T_\text{d}}{T_\text{u}} \right)$, then

$$P_{i,\text{o}} = \frac{D_{i,\text{o,t}} - D_\text{b}}{U_{i,\text{e,t}} - U_\text{b}} \times \frac{T_\text{u}}{T_\text{d}} \tag{24}$$

If $\bar{D}_{\text{b,ucl}} > 0{,}05 \times \frac{\sum\limits_{i=1 \rightarrow n} U_{i,\text{o,u}}}{n} \times \left(\frac{T_\text{d}}{T_\text{u}} \right)$, then

$$P_{i,\text{o}} = \frac{D_{i,\text{o,t}}}{U_{i,\text{e,t}}} \times \frac{T_\text{u}}{T_\text{d}} \tag{25}$$

7.7.3.4 These observed penetrations shall be averaged to determine an average observed penetration value, as shown in Equation (26):

$$\bar{P}_\text{o} = \frac{\sum\limits_{i=1 \rightarrow n} P_{i,\text{o}}}{n} \tag{26}$$

7.7.3.5 The standard deviation of the observed penetration shall be determined as shown in Equation (27):

$$\delta_\text{t} = \sqrt{\frac{\sum\limits_{i=1 \rightarrow n} (P_{i,\text{o}} - \bar{P})^2}{n-1}} \tag{27}$$

7.7.3.6 The observed penetration shall be corrected by the correlation ratio to yield the final penetration, as shown in Equation (28):

$$\bar{P} = \frac{\bar{P}_\text{o}}{\bar{R}} \tag{28}$$

7.7.3.7 The standard deviation of the correlation ratio shall be combined with the standard deviation of the observed penetration to determine the total error as shown in Equation (29):

$$\delta = \bar{P} \times \sqrt{\left(\frac{\delta_\text{c}}{\bar{R}} \right)^2 + \left(\frac{\delta_\text{t}}{\bar{P}_\text{o}} \right)^2} \tag{29}$$

7.7.3.8 The 95 % confidence limits of the penetration shall be determined as shown in Equations (30) and (31):

$$\bar{P}_\text{lcl} = \bar{P} - \left(\delta \times \frac{t}{\sqrt{n}} \right) \tag{30}$$

$$\overline{P}_{\text{ucl}} = \overline{P} + \left(\delta \times \frac{t}{\sqrt{n}} \right) \tag{31}$$

using the distribution variable, t, specified in Table 5 for a given number of samples, n.

7.7.3.9 The standard deviation and 95 % upper confidence limits for the background counts shall be determined using Equations (11), (12), (15) and (16).

7.7.4 Penetration data acceptance criteria

7.7.4.1 Penetration error limit

The number of sample runs, n, shall be at least three and sufficient to satisfy the conditions specified in Equations (32) and (33).

For particle size ranges 0,3 µm to 3 µm:

$$\left(\delta \times \frac{t}{\sqrt{n}} \right) \leqslant \left(0{,}07 \times \overline{P} \right) \text{ or } \left(\delta \times \frac{t}{\sqrt{n}} \right) \leqslant 0{,}05 \text{, whichever is greater.} \tag{32}$$

For particle size ranges 3 µm to 5 µm:

$$\left(\delta \times \frac{t}{\sqrt{n}} \right) \leqslant \left(0{,}15 \times \overline{P} \right) \text{ or } \left(\delta \times \frac{t}{\sqrt{n}} \right) \leqslant 0{,}05 \text{, whichever is greater.} \tag{33}$$

The requirement shall be satisfied by calculating this expression after each sample set and halting the testing sequence when the requirement is reached for each size range, or by acceptance criteria for a predetermined number of sample sets. If these conditions are met, $\overline{P}$ is used to calculate the efficiency.

7.7.4.2 Penetration calculation if penetration error limit not met

If the condition in 7.7.4.1 cannot be met[1], the sum of the upstream counts and the sum of the downstream counts shall be calculated, as shown in Equations (34), (35) and (36):

$$U'_{\text{t}} = \sum_{n=1 \to n} U_{i,\text{e,t}} \text{ (sequential)} \tag{34}$$

or

$$U'_{\text{t}} = \sum_{n=1 \to n} U_{i,\text{o,t}} \text{ (simultaneous)} \tag{35}$$

$$D'_{\text{t}} = \sum_{n=1 \to n} D_{i,\text{o,t}} \tag{36}$$

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[1] There are several reasons why the penetration error limit may not be met. Possible causes include but are not limited to: unsteady upstream concentration, unsteady shedding of particles from a partially loaded filter, and filter efficiency changing during the sampling periods. If the penetration error limit is consistently not met during the fractional efficiency before loading test, it is likely that the filter is loading enough during the sampling to change the efficiency.

The sums of the upstream and downstream counts are used to calculate an alternate upper confidence limit for observed penetration, P'_{ucl}, using Poisson statistics, as shown in Equation (37):

$$P'_{\text{ucl,o}} = \frac{D'_{\text{ucl,t}}}{U'_{\text{lcl,t}}} \tag{37}$$

For values $\leqslant 50$, $D'_{\text{ucl,t}}$ and $U'_{\text{lcl,t}}$ are given in Table B.1.

For values > 50, $D'_{\text{ucl,t}}$ and $U'_{\text{lcl,t}}$ are calculated as shown in Equations (38) and (39):

$$D'_{\text{ucl,t}} = D'_{\text{t}} + \left(2 \times \sqrt{D'_{\text{t}}}\right) \tag{38}$$

$$U'_{\text{lcl,t}} = U'_{\text{t}} - \left(2 \times \sqrt{U'_{\text{t}}}\right) \tag{39}$$

The observed upper confidence level penetration using Poisson statistics shall be corrected by the correlation ratio to yield the final upper confidence level penetration using Poisson statistics, as shown in Equation (40):

$$P'_{\text{ucl}} = \frac{P'_{\text{ucl,o}}}{\overline{R}} \tag{40}$$

The greater of the two upper confidence limits for penetration, $\overline{P}_{\text{ucl}}$ or P'_{ucl}, shall be used to calculate efficiency for that size range.

7.7.4.3 Penetration maximum background counts

For correlation tests and tests before dust loading, the 95 % upper confidence limits of the upstream and downstream background counts shall be < 5 % of the average estimated upstream count when the particle generation is on, as shown in Equation (41):

$$\overline{D}_{\text{b,ucl}}, \overline{U}_{\text{b,ucl}} < \frac{\sum\limits_{i=1 \to n} U_{i,\text{e,t}}}{n \times 20} \tag{41}$$

7.7.4.4 Penetration minimum upstream counts

The sum of the estimated upstream counts shall be $\geqslant 500$, as shown in Equation (42):

$$\sum_{i=1 \to n} U_{i,\text{e,t}} \geqslant 500 \tag{42}$$

7.7.5 Efficiency

Fractional efficiency is determined as shown in Equation (43):

$$E = (1 - P) \tag{43}$$

where P is replaced by $\overline{P}$ or $\overline{P}_{\text{ucl}}$ or P'_{ucl}, as determined in 7.7.4.1 and 7.7.4.2.

7.8 Procedure for loading and fractional efficiency

7.8.1 Test procedure

Particle size efficiency measurements shall be performed at intervals during the dust-loading procedure to establish a curve of efficiency as a function of dust loading. Efficiency curves shall be drawn for any or all of the particle size ranges of the test protocol. Efficiency measurements shall be made at the following points during the dust-loading procedure:

a) before any dust is fed to the device;

b) after the dust-loading increments have achieved a pressure loss increase of 10 %, 25 % and 50 % of the difference between the beginning and the prescribed end point limit of airflow resistance;

c) after the dust increment that loads the device to its prescribed end point resistance limit, as described in 3.7.

7.8.2 Adjusting for dust migration (re-entrainment of loading dust)

7.8.2.1 After dust loading and before efficiency measurements, airflow shall be maintained through the device for 20 min. Duration of less than 20 min is allowable if a release rate of no more than 5 % is obtained in each of the particle size ranges.

7.8.2.2 For the purposes of this part of ISO/TS 19713, the release rate is the ratio of the number of released test dust particles from the filter after a dust-loading increment to the average number of upstream aerosol particles challenging the test device during the determination of the efficiency for a specific size range.

The number of loading dust particles released, in percent, is calculated as shown in Equation (44):

$$\frac{D_{\mathrm{b,ucl}}}{\frac{1}{n}\left(\sum_{i=1\to n} U_{i,\mathrm{o,u}}\right)} \times \frac{T_{\mathrm{u}}}{T_{\mathrm{d}}} \times 100 \tag{44}$$

7.8.2.3 The efficiency of the air cleaner in a specific size range shall be reported as 0 % if during a test run for fractional efficiency in that range the fractional efficiency is negative.

7.9 Reporting results of loading tests

7.9.1 Results of loading tests shall be reported in the form of five fractional efficiency curves for the test device:

a) fractional efficiency before dust loading;

b) after each incremental dust loading, a total of three curves; and

c) at its final loading point.

7.9.2 The fractional efficiency results shall be plotted at the log mean diameter of the particle counter size range.

7.9.3 The minimum information to be included in the report is shown in Annex A. As a proposal, use the form in Annex A to report the results.

Annex A
(informative)

Test report

Engine air cleaners for light, medium and heavy duty vehicles
Fractional efficiency test report

1 Test unit

Manufacturer: ....
Type of filter media: ....
Air cleaner description and orientation: ....
Air filter description and orientation: ....
Pre-cleaner/pre-separators: ....

2 Test equipment

Test duct set-up and orientation

Dust feeder:
Contaminant for efficiency measurements (KCL)
Equipment: ....
Settings/feed rate: ....
Contaminant for loading (ISO 12103-1 A2 test dust)
Equipment: ....
Settings/feed rate: ....

Particle counter: Type: ....
Sample flow: ....

Neutralizer: Type: ....
Special settings: ....

3 Test conditions

Test flow rate (m^3/h): ....
Test termination criteria: ....

Temperature (°C): Before test: ....
After test: ....

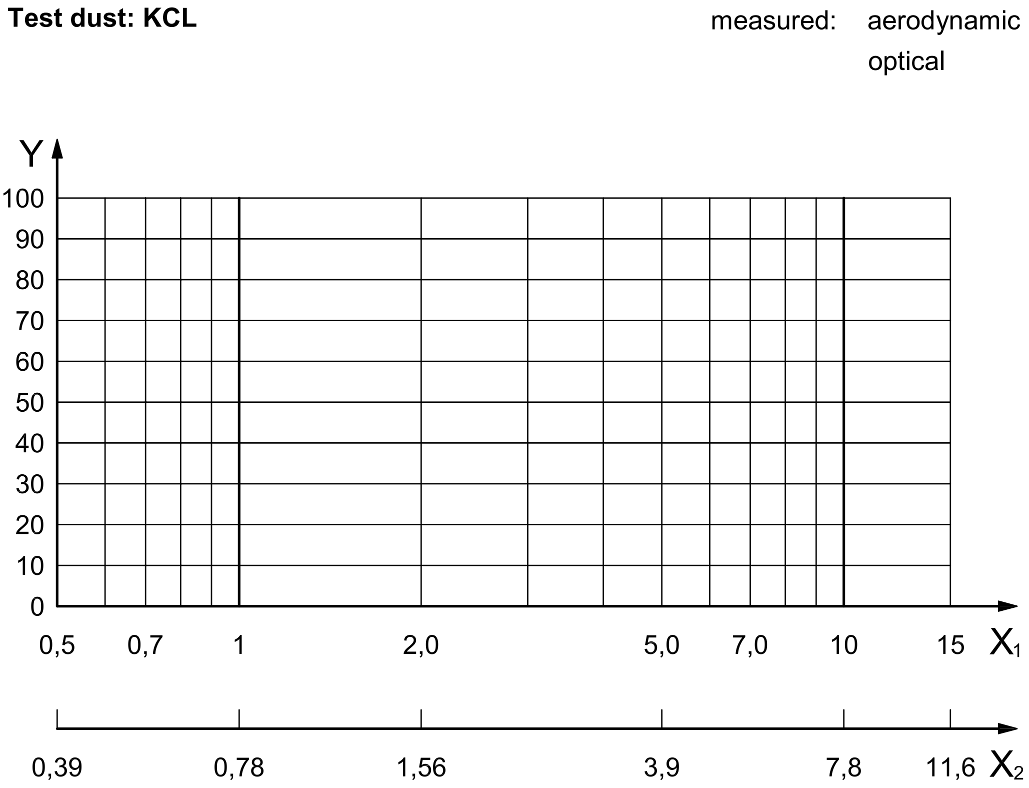
Barometric pressure (kPa): Before test: ....
After test: ....

Relative humidity (%): Before test: ....
After test: ....

Total cumulative counts ($counts/cm^3$): ....
Neutralization (yes/no): ....
Test termination (kPa): ....
Fractional efficiency intervals: ....
Initial restriction (kPa): ....

4 General comments

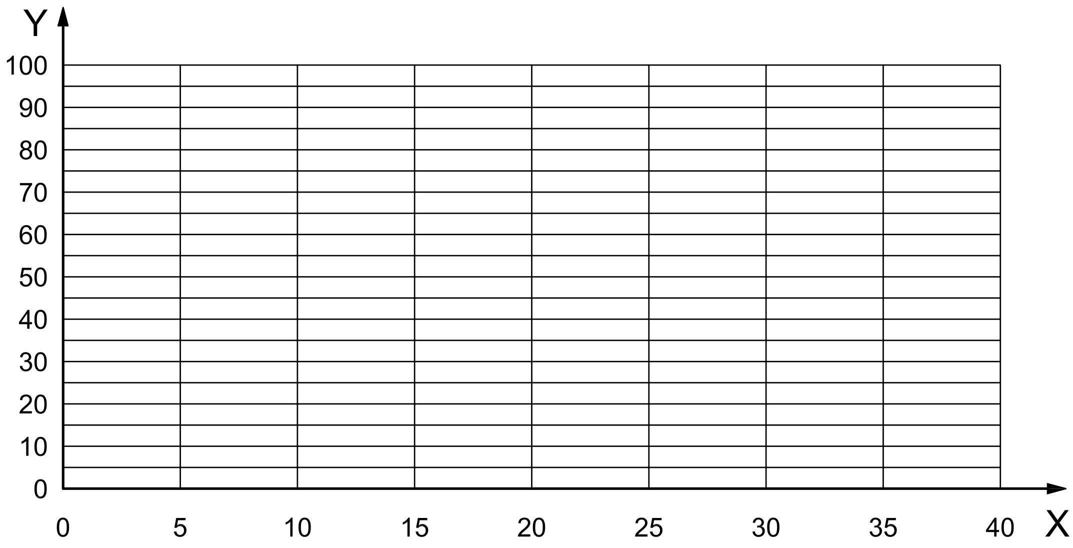
Date: .... Test conducted by: ....



Key

X1 aerodynamic particle diameter, in µm
X2 optical particle diameter, in µm
Y fractional filtration efficiency, in percentage

Figure A.1 — Fractional efficiency as a function of particle size and dust capacity at test flow rate



Key

X dust loading, in g
Y pressure difference, in Pa

Figure A.2 — Pressure loss versus aerosol loading

Annex B
(normative)

Poisson statistics

When using particle counters to evaluate fractional filtration efficiency, it is necessary to consider limitations imposed by this method. The efficiency is determined by comparing the particles detected and counted upstream of the air cleaner or air filter to the particles detected and counted downstream of the air cleaner or air filter. Inevitably, there are differences between the upstream and downstream sampling and detection equipment. Subclause 7.4 presents a method to calculate correlation ratios to minimize the errors due to the difference between the upstream and downstream equipment.

In the efficiency tests described in this part of ISO/TS 19713, at least three upstream and three downstream samples are counted. For sequential sampling systems, the average of the upstream counts before and after a downstream count is used to estimate the upstream count during the downstream sampling time. In this case, three or more penetration values are calculated and analysed for data quality using a t-test.

However, when the number of particles counted in a size class is low, potential uncertainty may occur as a result of counting a few randomly occurring events. In this case, it may be difficult or impossible to meet the penetration error limits in 7.7.4.1, hence an alternative method to quantify the size of the potential error from counting a few particles is presented in 7.7.4.2. Because the error due to counting random events is a function of the total number of particles counted, it is important to work with the actual counts, and not concentrations or averages. For the calculations in 7.7.4.2, the sum of the estimated upstream counts is used along with the sum of the actual downstream counts.

When a well-mixed, stable aerosol penetrates a filter, penetrating particles will appear downstream of the filter (or in a small downstream air sample) randomly, but at some average rate. Of importance to efficiency testing is the relationship between the results of a single sample or a finite set of samples and the true mean result. This relationship between an observed result and the confidence limits on the true mean result is described by Poisson statistics.

Table B.1 gives the 95 % confidence limits on a single observed particle count, N, when $N \leqslant 50$.

For a single observed particle count, N, there is a 95 % confidence that the true mean count is between the upper and lower limits given by Table B.1.

For particle counts > 50, Equations (35) and (36) are used to estimate the confidence limits.

Table B.1 — 95 % confidence limits for the mean value of a Poisson variable

Observed count *N*	Lower limit	Upper limit
0	0,0	3,7
1	0,1	5,6
2	0,2	7,2
3	0,6	8,8
4	1,1	10,2
5	1,6	11,7
6	2,2	13,1
7	2,8	14,4
8	3,5	15,8
9	4,1	17,1
10	4,8	18,4
11	5,5	19,7
12	6,2	21,0
13	6,9	22,3
14	7,7	23,5
15	8,4	24,8
16	9,2	26,0
17	9,9	27,2
18	10,7	28,4
19	11,4	29,6
20	12,2	30,8
21	13,0	32,0
22	13,8	33,2
23	14,6	34,4
24	15,4	35,6
25	16,2	36,8
26	17,0	38,0
27	17,8	39,2
28	18,6	40,4
29	19,4	41,6
30	20,2	42,8
31	21,1	44,0
32	21,9	45,1
33	22,7	46,3
34	23,5	47,5
35	24,4	48,7
36	25,2	49,8
37	26,1	51,0
38	26,9	52,2
39	27,7	53,3
40	28,6	54,5
41	29,4	55,6
42	30,3	56,8
43	31,1	57,9
44	32,0	59,0
45	32,8	60,2
46	33,7	61,3
47	34,5	62,5
48	35,4	63,6
49	36,3	64,8
50	37,1	65,9

NOTE See Reference [17].

Annex C
(normative)

Pressure loss data reduction

If the temperature and pressure at the filter under test are different from the standard conditions of 20 ± 5 °C and 101,3 kPa, then the measured pressure loss shall be corrected to indicate the pressure loss that would be measured if the conditions were standard.

The correction required for the pressure loss measurement depends on the test conditions and on the type of air cleaner or air filter being tested. For tests in accordance with this part of ISO/TS 19713, the temperature shall be controlled to the standard temperature so the primary variable is the absolute pressure at the unit under test. This part of ISO/TS 19713 requires that the test be conducted at specified actual volume flow rates in order to minimize changes in the efficiency measurement due to different velocities. Therefore, if the absolute pressure at the filter under test is not standard pressure, then the measured filter pressure loss is corrected as follows.

NOTE 1 This correction to the pressure loss of the air cleaner or air filter is independent of the corrections required for the flow rate measurement device that are required to establish the correct actual volume flow rate at the air cleaner or air filter under test.

Measure the unit pressure loss, ΔP, as a function of volume flow rate, Q, or at a set flow rate, Q. Plot the measured pressure loss, ΔP_m, as a function of the measured flow rate, Q_m. Note that in this test method, Q_m is the actual volume flow rate at the filter at the test conditions. Find K_1 and K_2 by doing a least squares curve fit of Equation (C.1) to the data:

$$\Delta P_\mathrm{m} = (K_1 \times \eta_\mathrm{m} \times Q_\mathrm{m}) + \left(K_2 \times \rho_\mathrm{m} \times Q_\mathrm{m}^2\right) \tag{C.1}$$

where

η_m is the dynamic viscosity of air in the unit at the test conditions;

ρ_m is the mass density of air in the unit at the test conditions.

Use Equation (C.2) to calculate the standard filter pressure loss, ΔP_s, at the specified flow rate in the range of flow rates measured. Extrapolation to flow rates outside the measured range is not recommended.

$$\Delta P_\mathrm{s} = (K_1 \times \eta_\mathrm{s} \times Q_\mathrm{s}) + \left(K_2 \times \rho_\mathrm{s} \times Q_\mathrm{s}^2\right) \tag{C.2}$$

where

η_s is the dynamic viscosity of air at standard conditions;

ρ_s is the mass density of air at standard conditions;

Q_s is the flow at standard conditions.

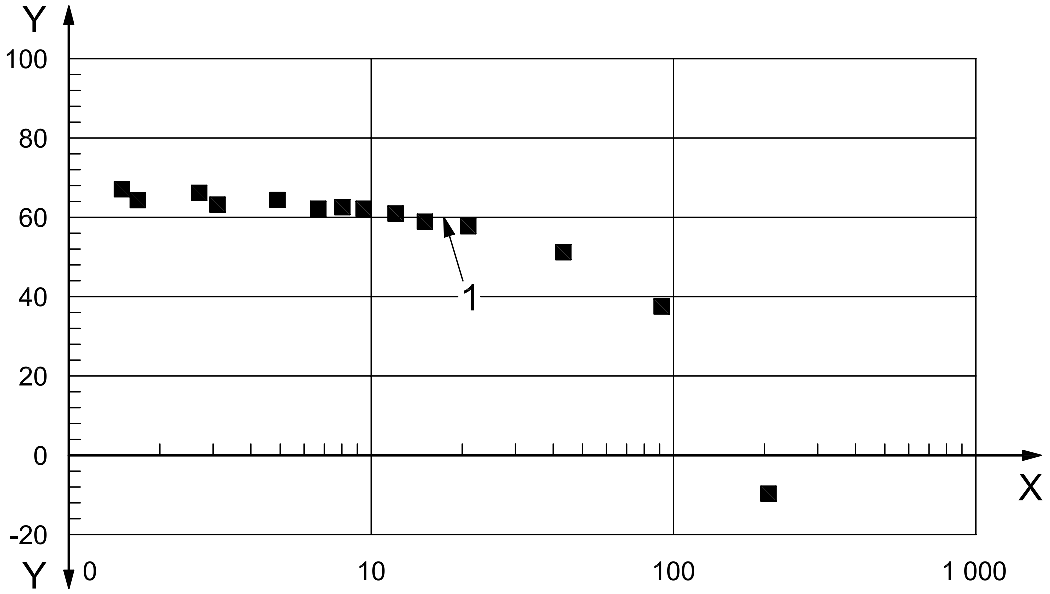
NOTE 2 Since the temperatures are controlled to standard conditions, the correction due to the ($K_1 \times \eta_\mathrm{s} \times Q$) term will be negligible.

Annex D
(informative)

Determination of maximum efficiency aerosol concentration

In 5.2.14, it is recommended to perform fractional efficiency tests versus particle concentration for particle size ranges using particle counters. An example is illustrated in Figure D.1. When the concentration is low, the fractional efficiencies are not stable due to lack of enough counts as seen on the left-hand side of the curves. The fractional efficiencies will then be stable over a range of particle concentrations. As the particle concentration is further increased, the efficiency of the lowest size channel will start to drop due to coincidence problem. The appropriate particle concentration range should be the range in which the fractional efficiencies are stable (e.g. approximately 5 to 15 particles per cubic centimetre for the 0,3 μm to 0,5 μm channel shown in Figure D.1). It should be noted that the appropriate particle concentration range for different size distributions of challenge aerosol and for different particle counters may be different. The tests described here should be performed when different counters or different challenge aerosols are used.

Overloading test of particle counter
Filter efficiency in smallest size channel



Key

X total concentration

Y filtration efficiency, in percentage

1 upper limit for testing

Figure D.1 — Example of efficiency at various sizes versus particle counts

Annex E
(normative)

Accuracy requirements, validation and routine operation

Tables E.1 to E.3 provide lists of the items that need to be designed, verified, measured, calibrated or certified to ensure that a test system meets the requirements of this part of ISO/TS 19713. This part of ISO/TS 19713 describes the required performance of the test system, rather than requiring specific hardware and specific procedures. Hence, it is up to the builder and user of the test system to verify that the required performance is in fact achieved.

Table E.1 contains instrumentation accuracy and other requirements that are generally established by the instrumentation used in the test system. The criteria for most items in Table E.1 are met with traceable calibration.

Table E.2 contains system characteristics that are established by system design. These characteristics need to be measured once to verify the system design and to verify the initial performance of the test system. The criteria for most items in Table E.2 are verified by measurement of the characteristic of the test system.

NOTE Requirements for documenting the test system validation are given in 5.4.

Table E.3 contains calibrations, measurements and activities that need to be repeated on a scheduled basis to ensure the continued repeatability and reproducibility of the test system.

Clause numbers in Tables E.1 to E.3 refer to the clauses of this part of ISO/TS 19713 in which the information may be found.

Table E.1 — Instrument accuracy requirements

Clause	Description	Criteria	Comments
ISO 5011:2000, Clause 4	Airflow rate measurement accuracy	±2 % of reading	±2 % repeatability
—	Air velocity measurement accuracy	±3 % of reading	—
—	Pressure loss measurement accuracy	±1 % of reading	—
5.3	Temperature measurement accuracy	±5 ºC	—
5.3	Relative humidity measurement accuracy	±2 % RH	—
—	Barometric pressure measurement accuracy	±300 Pa	—
5.2.13.2	Particle counter size range	0,3 µm to 5 µm and 0,5 µm to 10 µm	Geometric aerodynamic

Table E.2 — Validation (measurement devices and procedures)

Clause	Description	Criteria	Comments
	Test system, conductive and grounded	—	Verify with continuity tester
5.2.5	Temperature control	(20 ± 5) °C	In accordance with ISO 5011
5.2.5	Relative humidity control	(55 ± 15) % RH	In accordance with ISO 5011
5.2.9	Test duct air leakage	—	Verify by inspection
Table E.1	Flow rate control accuracy, shall be accurate as mounted in system	±5 % accuracy	±2 % repeatability
5.2.8	Airflow uniformity	±10 %	—
Annex E	Pressure loss measurement accuracy	±2 %	—
5.2.12	Sample probe isokinetic	0 % to ±20 %	By calculation from flow rates and diameters
5.2.12	Sample probe location, upstream, centred, close to filter centred at least $7 \times D$ downstream and $4 \times D$ upstream of any bends and obstructions	—	—
5.2.12	Sample probe location, downstream, centred, at least $7 \times D$ downstream and $4 \times D$ upstream of any bends and obstructions	—	—
5.2.12	Sample line design and conductivity	—	Inspection and electrical continuity to ground
5.2.11	Aerosol, fraction efficiency, charge neutralized	See Annex G	—
5.2.10	Aerosol, fraction efficiency, dryness	As needed	Applies to KCl aerosol only
7.7.4	Fractional efficiency aerosol, concentration low enough so there is no change in efficiency during test (i.e. no loading effects)	This is established on a clean filter	For validation, it is recommended that this test be done for n = 10 repetitions rather than n = 3
5.2.13	Dust feeder for loading aerosol, stable concentration	±5 %	Same as ISO 5011
5.2.13	Dust feeder for loading aerosol, concentration	1 g/m^3	Same as ISO 5011
5.2.12	Dust feeder for loading aerosol, size distribution in test duct	—	Use ISO 5011 dust injector or demonstrated equivalent
5.2.13	Particle counters, primary size calibration with PSL	—	In accordance with manufacturer specification
5.2.14.4	Aerosol, fraction efficiency, concentration below particle counter limit to prevent coincidence	Maximum of 5 % decrease	Procedure in Annex D
5.4, j)	Repeatability, pressure loss and efficiency	±5 %	To be done at start-up and annually
5.4	Reference filter test	Set baseline	Use to monitor changes in test system performance
5.4	Performance certification documentation	Not applicable	For the test system validation to be complete it shall be documented

NOTE The order in which the validation tests are done is important. The order given in this table can be used as a guide. See also Table E.3.

Table E.3 — Routine operation

Clause	Description	Criteria	Frequency[a]	Comments
—	Pressure loss across empty test clause (tare pressure loss)	—	As required to maintain accuracy	—
5.6.2	Particle counter zero check	—	Weekly	Maximum 10 counts per minute per channel
5.2.11	Confirmation of neutralizer radioactivity or ionizer current	Follow 5.2.10 See Annex G	If electret reference filter test indicates a problem	Also clean every 100 hours of operation
6	Reference filter pressure loss and fractional efficiency before dust loading	—	As required to maintain accuracy	Track for changes Recommended daily tests
5.2.14	Particle measurement device calibration	—	Annually	In accordance with manufacturer specification
5.2.8	Airflow uniformity	±10 %	Hardware change	Each new filter mounting geometry or after any changes to the test system
5.2.10.3	Efficiency aerosol, uniformity (within each size channel) 0,3 µm to 5 µm and 5 µm to 10 µm	±10 % and ±20 %	Hardware change	Each new filter mounting geometry or after any changes to the test system
5.2.13	Dust feeder for loading aerosol, stable concentration	±5 %	New design or test flow rate	—
5.2.13	Loading test aerosol concentration	1 g/m^3	As required to maintain accuracy	See ISO 5011
—	Efficiency aerosol generator response time	—	Annually or change	—
Annex D	Coincidence error	—	Annually or change	—
5.2.7	Leak test	—	After every test	Visual inspection
Annex E	Calibration of airflow measurement	±2 %	Annually	—
Annex E	Calibration of pressure loss measurement	±2 %	Annually	—
Annex E	Calibration of other instrumentation (temperature, relative humidity, etc.)	±5 %	Annually	In accordance with instrument manufacturer's recommendations or annually
—	Cleaning of test duct and components	—	After every test	As needed

[a] Change refers to any change in the test system that might affect the performance.

Annex F
(normative)

Aerodynamic diameter

To be able to describe the properties of non-spherical particles, the definition of equivalent diameters is necessary. For example, the deposition of airborne particles in a filter, transportation losses in ducts, and the behaviour of particles in the human respiratory tract are based on the particle's aerodynamic properties. Therefore, the aerodynamic diameter is used to characterize particles in these cases.

The aerodynamic diameter is the diameter of a sphere of density 1 g/cm^3 with the same terminal velocity due to gravitational force in calm air, as the particle, under the prevailing conditions of temperature, pressure and relative humidity$^{2)}$.

The aerodynamic diameter, D_ae, is defined as

$$D_\text{ae} = \left(\frac{C_\text{c}\left(D_\text{g}\right) \times \rho}{C_\text{c}\left(D_\text{ae}\right) \times \rho_\text{o} \times \chi} \right)^{1/2} \times D_\text{g} \qquad \text{(F.1)}$$

where

D_g is the geometric (volume equivalent) diameter of the particle, in g/cm^3;

ρ is the density of the test dust particle, in g/cm^3;

ρ_o is the unit density, 1g/cm^3;

C_c is the slip correction factor;

χ is the dynamic shape factor of the test dust particle.

For particle bulk material densities between 0,5 g/cm^3 and 3 g/cm^3 and particles aerodynamically larger than 0,5 µm, Equation (F.1) simplifies to

$$D_\text{ae} = \left(\frac{\rho}{\rho_\text{o} \times \chi} \right)^{1/2} \times D_\text{g} \qquad \text{(F.2)}$$

with a relative size error less than 5 %. The densities and shape factors specified in Table F.1 shall be used.

---

2) For particles of aerodynamic diameter less than 0,5 µm, the particle diffusion diameter should be used instead of the particle aerodynamic diameter. The particle diffusion diameter means the diameter of a sphere with the same diffusion coefficient as the particle under the prevailing conditions of temperature, pressure and relative humidity.

Table F.1 — Density and shape factors

Efficiency aerosol	**Density** ρ g/cm^3	**Dynamic shape factor** χ
ISO 12103-1 A2 test dust	2,65	1,57
KCl	1,97	1,20

An optical particle counter measures the optical equivalent diameter, where the light scattered by the particle equals the light scattered by a calibration particle (e.g. PSL) of known size. For precision work, an optical particle counter may be calibrated with the material to be measured. In that case, the optical equivalent diameter equals the geometric diameter and, consequently, Equation (F.2) can be used directly.

Otherwise, the conversion of the optical equivalent diameter of the particles into the geometric (volume equivalent) diameter before applying Equation (F.2) is required to minimize the conversion error. For the purposes of this part of ISO/TS 19713, use the optical equivalent diameter as the geometric (volume equivalent) diameter for calculating the aerodynamic equivalent diameter, which is current practice.

Annex G
(normative)

Method to test efficiency aerosol for proper neutralization

G.1 Overview

Neutralized aerosol is defined as aerosol whose charge distribution is reduced until it provides a Boltzman equilibrium charge distribution.

NOTE 1 The aerosol is not neutral in the sense that all individual particles are neutral.

NOTE 2 It might not be possible to obtain a true Boltzman equilibrium charge distribution in the short time available in a test system. The procedures in this annex are designed to minimize the effect of excess charge arising from the aerosol generation method.

This annex contains methods to determine if the efficiency test aerosol is properly neutralized as required in 5.2.11. It is very difficult, costly and time consuming to directly measure the charge distribution on the aerosol, hence the test methods described in this annex are indirect. The two methods described in detail are based on the effect of particle charge on the efficiency of electret filter media. Electret filters collect charged particles more efficiently than uncharged particles. Other methods are mentioned briefly.

- Method 1 involves reducing the concentration/flow rate to minimize electret efficiency. It is applicable to radioactive-type neutralizers and may also be used to check the concentration capabilities of electrostatic corona neutralizers.
- Method 2 involves adjusting the ion output to minimize electret efficiency. It is only applicable to electrostatic corona-type neutralizers.

Both test methods find the minimum electret efficiency that can be obtained with the neutralizing equipment being tested. That does not necessarily mean that the aerosol is neutralized to the Boltzman equilibrium state. Nor does it mean that the aerosol is sufficiently neutralized to obtain repeatable efficiency measurements or to obtain efficiency measurements that will match other test systems. However, when these methods are not followed, it has been demonstrated that widely varying efficiency measurements can result. Some evidence exists that when these methods are followed, much better reproducibility is achieved.

The other methods listed here are not described in detail as they depend on expensive instrumentation that is not available in all filter test laboratories, or they depend on instrumentation that is in development and is not commercially available at the time of publication of this part of ISO/TS 19713, or they are very time consuming and require custom equipment (some of the custom equipment involve potentially dangerous voltages). The list gives measurement methods; each of these measurement methods would be used in a procedure similar to those described below to determine the appropriate concentration for radioactive-type neutralizers or the operating parameters for corona-type neutralizers:

a) measure the neutral fraction utilizing a photometer after passage of an electrostatic particle trap and maximize the neutral fraction;

b) measure the neutral fraction utilizing a particle sizing instrument after passage of an electrostatic particle trap and maximize the neutral fraction;

c) measure the net charge deposited on the filter being tested. Adjust the neutralizer to minimize the net charge (it should be zero);

d) measure the net charge on the aerosol using an aerosol electrometer and minimize net charge on the aerosol (it should be zero);

e) measure the charge distribution using a range of voltages in an electrostatic particle trap and a particle sizing instrument and compare to Boltzman distribution.

G.2 General procedure

The general procedure includes installation, verification, maintenance and re-verification:

a) install appropriately sized aerosol neutralizer;

b) verify that it is functioning properly and adjust as needed using the methods in this annex;

c) measure and record the operating parameters: ionizer currents and/or voltages, radioactivity level, flow rate, aerosol concentration, etc.;

d) periodically verify continued operation by checking an electret reference filter and other properties (e.g. ionizer current, radioactivity, etc.): the period is to be determined by the test system operator;

e) periodically clean and maintain neutralizer;

f) periodically re-verify proper functioning using the methods in this annex.

G.3 Description of filter to be used

Both test methods depend on the use of a filter made with electret filter media. It is important to use a filter that has a large part of its efficiency due to electrostatic filtration mechanisms so the effect is easily measured. It is suggested that the fractional efficiency before dust loading in the 0,3 µm to 0,5 µm size range should be in the range of 20 % to 40 % when tested with a properly neutralized aerosol. For example, filters made with the following types of filter media will be suitable for this test:

— media made from fibres formed by slitting or shredding a thin, highly charged polymeric film; fibre cross-sections are approximately (5 × 30) µm;

— media made from a mixture of two types of polymeric fibres that become highly charged by tribo-electric mechanisms during manufacture; fibres are approximately (10 × 20) µm.

Other filters in which the fibres are relatively large and the mechanical filtration mechanisms (diffusion, interception, and inertial) contribute only a minor part of the overall efficiency of the filter media may be used.

Filters made with such media and having 20 % to 40 % efficiency when tested with properly neutralized aerosol may have efficiencies up to 90 % or higher if tested with charged (improperly neutralized) aerosol.

To confirm that electrostatic forces are the primary filtration mechanism, measure the filter efficiency before and after discharging the filter. One possible method to discharge an electret filter is to soak it in windshield washer fluid. The efficiency after discharge should be less than half the original efficiency.

If a full size filter made from appropriate electret media is not available, it is possible to insert a flat sheet media holder into the sample line of the downstream particle counter; then all that is needed is a small sample of electret media. The size of the media holder should be such that the velocity through the media is on the order of 0,1 m/s.

G.4 Method 1: reduce concentration/reduce flow rate to minimize electret efficiency

G.4.1 Procedure

a) Remove radioactive neutralizer (or turn off ionizer) and measure and record the efficiency of electret filter.

b) Install neutralizer (or turn on ionizer) and measure and record the efficiency.

c) Reduce particles passing through the neutralizer per unit time by a factor of 2. This can be accomplished by reducing the concentration of aerosol passing through the neutralizer or by reducing the flow through the neutralizer. Maintain the same airflow through the filter for all tests. Measure and record the efficiency.

d) Remove neutralizer (or turn off ionizer) measure and record the efficiency.

G.4.2 Analysis

Plot efficiency for the smallest size range as a function of particle flux (concentration or flow rate) through the neutralizer.

If efficiencies measured in steps a) and d) of G.4.1 are different, then the properties of the filter may be altered by the filter test, i.e. it is loading and increasing efficiency due to mechanical filtration mechanisms or the electret is degrading and losing efficiency. If the properties of the filter are being altered by the test, then either the efficiency test aerosol concentration will need to be reduced or the duration of the test will need to be reduced and the tests repeated.

If efficiencies a) to d) are all the same, either the aerosol is not being charged during the process of aerosolizing it, or the neutralizer is not working.

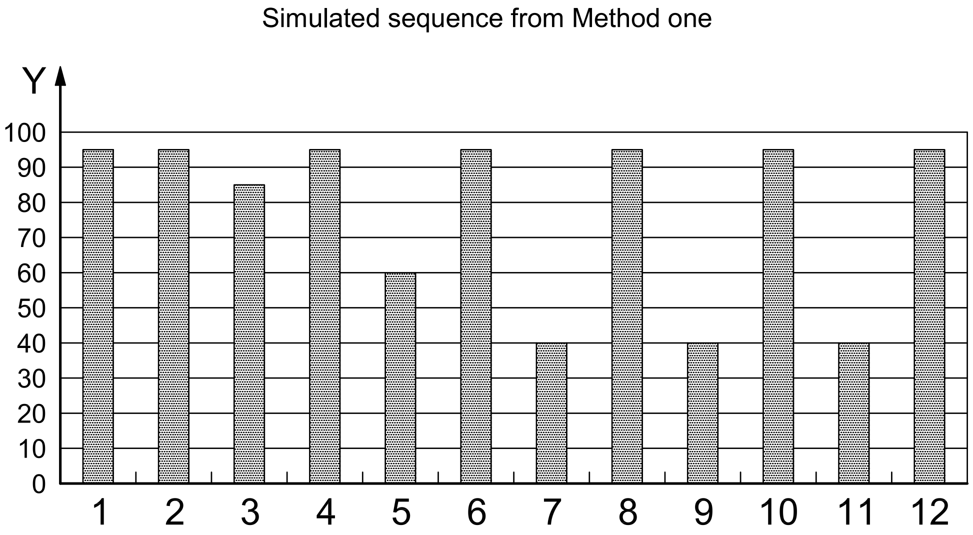
If efficiencies b) or c), or both, are less than efficiencies a) and d), then the aerosolization process charges the aerosol and the aerosol neutralizer is at least partially neutralizing the aerosol.

If efficiencies b) and c) are the same and are less than efficiencies a) and d), it is likely that the neutralizer is adequately neutralizing the aerosol. In this case, repeat the procedure and increase the particles passing through the neutralizer per unit time by a factor of 2, and measure the efficiency.

If efficiency c) is lower than efficiency b), then the neutralizer is not adequately neutralizing the aerosol for the concentration in step b). In this case, repeat the procedure and reduce the particles passing through the neutralizer per unit time by another factor of 2 and measure the efficiency. Repeat until reducing the particle flux by a factor of 2 does not reduce the measured efficiency.

It is important to continue to check the efficiency with the neutralizer removed (or the ionizer turned off), in order to verify that the electret efficiency is not changing due to loading or electret discharging.

See Figure G.1 for an example of a simulated sequence of the Method 1 test.



Key

Y	measured efficiency in smallest size range, in percentage
1	1st no neutralizer
2	particle flux A
3	particle flux A/2
4	2nd no neutralizer
5	particle flux A/4
6	3rd no neutralizer
7	particle flux A/8
8	4th no neutralizer
9	particle flux A/16
10	5th no neutralizer
11	particle flux A/32
12	6th no neutralizer

NOTE In this figure, particle flux A/16 is the highest flux that can be used. The 6th no neutralizer test shows that the electret is beginning to degrade.

Figure G.1 — Graphic example of Method 1

G.4.3 Action

Operate the neutralizer at one-half of the highest particle flux for which the efficiency is the same as the next lower particle flux.

G.5 Method 2: adjust ion output to minimize electret efficiency

G.5.1 General

This method applies only to powered corona-type ion sources that have adjustable voltage/current levels for both the positive and negative coronas. There are three phases in this test method. In the first phase, the proper excitation method is determined. In the second phase, the ratio of positive to negative ions is established. In the third phase, the proper concentration of ions is determined. Within each phase some iteration (repeat testing while adjusting the settings) is required to get the best results. There is also a need to repeat the three phases as adjustments made in one phase may affect the results in another phase. Because the method may require several iterations, it is important to carefully monitor the condition of the electret filter as described in the procedure for changes due to the testing.

G.5.2 Procedure

G.5.2.1 Excitation type

Corona-type ion sources can be operated in steady state (d.c.) mode, in a pulsed mode or in an a.c. mode. With steady state modes, recombination of the positive and negative ions may occur before the aerosol is properly neutralized. In pulsed or a.c. modes, it is possible to increase the charge on particles if there is not sufficient mixing.

Prior to doing the following tests, take ionizer out of the test system and aim the ionized air stream at the static voltmeter or place an electrostatic voltmeter in the test system in the stream of ionized air. Adjust the controls of the ionizer to obtain a 0 V reading.

a) Reinstall the ionizer or remove the static voltmeter from the test system.

b) With the ionizer turned off, measure and record the efficiency of the electret filter.

c) Turn on neutralizer, measure and record the efficiency.

d) Adjust the pulsing mode and frequency to minimize the measured efficiency of the electret filter. The effect is most noticeable in the small particle size ranges. Measure and record the efficiency. Note that some modes may cause the efficiency to be higher than when the ionizer is turned off, as in step b). This is because the aerosol is being charged rather than neutralized.

e) Turn off ionizer, measure and record the efficiency. If the efficiency is different from that measured in step b), then the test is affecting the charge on the filter media. If this happens, the efficiency test aerosol concentration will need to be reduced or the duration of the test will need to be reduced and the tests repeated.

G.5.2.2 Balancing

Prior to doing the following tests, take ionizer out of the test system and aim the ionized air stream at the static voltmeter or place an electrostatic voltmeter in the test system in the stream of ionized air. Adjust the controls of the ionizer to obtain a 0 V reading.

a) Reinstall the ionizer or remove the static voltmeter from the test system.

b) With the ionizer turned off, measure and record the efficiency of the electret filter.

c) Turn on neutralizer, measure and record the efficiency.

d) Adjust the positive and/or negative corona current or voltage to minimize the measured efficiency of the electret filter. The effect is most noticeable in the small particle size ranges. Measure and record the efficiency. Note that conditions may cause the efficiency to be higher than when the ionizer is turned off, as in step b). This is because the aerosol is being charged rather than neutralized.

e) Turn off ionizer, measure and record the efficiency. If the efficiency is different from that measured in step c), then the test is affecting the charge on the filter media. If this happens, the efficiency test aerosol concentration will need to be reduced or the duration of the test will need to be reduced and the tests repeated.

G.5.2.3 Concentration

The balancing phase shown in G.5.2.2 is a prerequisite for this test.

a) With the ionizer turned off, measure and record the efficiency.

b) Turn ionizer on. Measure and record the efficiency.

c) Reduce particles passing through the neutralizer per unit time by a factor of 2. This can be accomplished by reducing the concentration of aerosol passing through the neutralizer or by reducing the flow through the neutralizer. Maintain the same airflow through the filter for all tests. [Rather than reducing the particle flux, the same effect can be created by increasing the ionizer current from step b). It is necessary to rebalance the positive and negative corona current or voltage as in the balancing phase to minimize the measured efficiency.] Measure and record the efficiency.

d) Turn off ionizer, measure efficiency. If the efficiency is different from that measured in step a), then the test is affecting the charge on the filter media. If this happens, the efficiency test aerosol concentration will need to be reduced or the duration of the test will need to be reduced and the tests repeated.

G.5.3 Analysis

Plot efficiency for the smallest size range as a function of current, voltage or particle flux (concentration or flow rate) through the neutralizer.

If efficiencies measured in steps a) and d) of G.5.2.3 are different, then the properties of the filter may be altered by the filter test, i.e. it is loading and increasing efficiency due to mechanical filtration mechanisms or the electret is degrading and losing efficiency. If the properties of the filter are being altered by the test, then either the efficiency test aerosol concentration will need to be reduced or the duration of the test will need to be reduced.

If efficiencies a) to d) are all the same, either the aerosol is not being charged during the process of aerosolizing it, or, more likely, the neutralizer is not working.

If efficiencies b) or c), or both, are less than efficiencies a) and d), then the aerosolization process charges the aerosol and the aerosol neutralizer is at least partially neutralizing the aerosol.

If efficiencies b) or c), or both, are more than efficiencies a) and d), then the aerosol is being charged by neutralizer rather than neutralized.

If efficiencies b) and c) are the same and they are less than efficiencies in a) and d), it is likely that the neutralizer is adequately neutralizing the aerosol. In this case, increase the particles passing through the neutralizer per unit time by a factor of 2 and measure the efficiency. [Rather than increasing the particle flux, the same effect can be created by decreasing the ionizer current from step b). It is necessary to rebalance the positive and negative corona current or voltage as in the balancing phase to minimize the measured efficiency.]

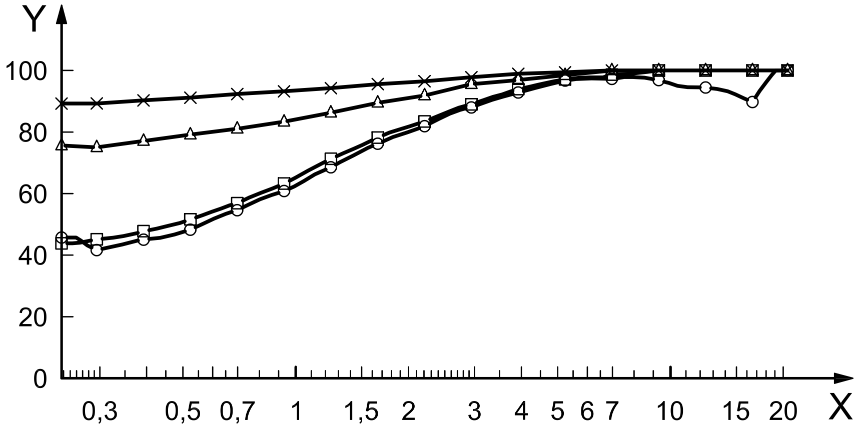
If efficiency c) is lower than efficiency b), then the neutralizer is not adequately neutralizing the aerosol in step b). In this case, repeat the procedure and reduce the particles passing through the neutralizer per unit time by another factor of 2 (or increase the ionizer current) and measure the efficiency. Repeat until reducing the particle flux by a factor of 2 (or increasing the ionizer current) does not reduce the measured efficiency.

It is important to continue to check the efficiency with the neutralizer removed (or the ionizer turned off) to verify that the electret efficiency is not changing due to loading or electret discharging.

G.5.4 Action

Operate the neutralizer at one-half of the highest particle flux for which the efficiency is the same as the next lower particle flux.

Figure G.2 shows fractional efficiency curves from a series of tests using a corona-type neutralizer with different concentrations.



Key

X concentration of corona-type neutralizer

Y fractional separation efficiency, in percentage

NOTE Source: Mölter, L. et al., *Mindestanforderungen an einen Referenz-Filterprüfstand — Filtrieren und Separieren 16* (2002), Nr. 3.

Figure G.2 — Fractional separation efficiency, flatsheet measurement, neutralization with corona ion source

Annex H
(normative)

Leakage

H.1 General

The November 1996 draft of ASHRAE 52.2[5] specifies maximum leak rates around 1 % of the test and total airflow rate. Later drafts may have changed or clarified that specification.

The test procedure in the above-mentioned draft uses a pressurized flow system, which makes leaks less critical regarding particle counting. To evaluate the leakage, it specifies blocking off the ductwork and measuring the flow required to maintain a pressure condition referenced to three specified test flow rates.

A similar scheme could be used, blocking off a specified section of the ductwork (although possibly only the critical section including the upstream and downstream probes). That would require putting in an elbow, the panel filter test housing, or other tube section in the test specimen location.

H.2 Types of leaks

H.2.1 Upstream leaks

Leaks in the inlet HEPA filtration will be seen at both the upstream and downstream sample locations. If these leaks are too large, the minimum system cleanliness level without the challenge feeder operating may not be achievable. If the concentration and size distribution of the aerosol in the leakage flow is consistent and a low enough level to be overwhelmed by the challenge aerosol, it may be acceptable. If it is inconsistent, it may affect the correlation values established for the particle counters.

H.2.2 Leaks between the upstream probe location and the system under test

These leaks will basically add to the feed aerosol. If consistent and accounted for in the correlation, they should not affect the fractional results significantly. Plugging and testing that section of ductwork should easily eliminate these leaks. Note that this section includes the loading dust feeder, injection system. Both the compressed air and suction lines of the dust injector will need to be shut off to keep ambient air from leaking in when doing a correlation or measuring the fractional efficiency.

H.2.3 Leaks in the test housing

If the application air cleaner housing is used, these leaks will be inevitable. They should only be present upstream of the test filter unless the housing is defective. Typical housings are not sealed on the dirty side of the filter, unless the air cleaner system is designed to be used for flow in either direction. Since these leaks are upstream of the filter their effect will be similar to those in type 2. In some cases the leakage can be minimized by taping off water drain holes, access covers and dust evacuation ports. It will also be very helpful to keep the ambient aerosol concentrations very low to minimize the effect of housing leakage. This is probably the most difficult type of leakage to deal with in the test procedure.

H.2.4 Leaks in the plumbing downstream of the test item and upstream of the downstream sample probe

These leaks will affect fractional efficiency significantly. Since leakage here is downstream of the test filter, it will increase during the test. Since it will always decrease the measured efficiency, it will be in the interest of the tester to eliminate this leakage. This assumes higher (actual) efficiency results are the objective. Leakage here can also be detected by closing off the plumbing and running a traditional leak flow test at expected vacuum levels. An alert to the possibility of leakage here would be if negative efficiencies are observed in the small size ranges.

H.2.5 Leaks downstream of the downstream probe

Leaks here will have minimal effect on the fractional results, assuming they are not gross. Gross leaks may add to absolute weights, and cause errors in actual flow rate in the test article. Leaks here may also contaminate the flow measurement device, causing errors.

H.2.6 Other leaks

Leaks in the sample lines themselves need to be detected and eliminated. Leaks inside particle counters can be a problem for which checks need to be made. The downstream counter in particular will be operating at a higher vacuum level.

Annex I
(informative)

Aerosol isokinetic sampling

Fractional efficiency defines the ability of an air filter to remove particles of given sizes, and is measured by comparing upstream and downstream particle concentrations during laboratory testing. A major factor in making this measurement is the ability to collect representative samples for analysis. Isokinetic sampling, including proper probe alignment, provides a method for obtaining representative samples at the inlets of upstream and downstream sampling probes. Isokinetic sampling, using thin-walled, sharp-edged tubes or nozzles, ensures that there is no distortion of the streamlines at the nozzle inlet and, therefore, no loss or gain of particles regardless of their size or inertia. Sampling is considered isokinetic when the probe is aligned parallel to the air streamlines and the air velocity entering the probe is the same as the free stream velocity approaching the inlet, as shown in Figure I.1 a), with $V_\mathrm{S} = V_\infty$.

In most cases, for circular ducts, the probe inlet is located along the duct centreline, parallel to the flow, facing upstream, at least four to six diameters from bends or obstructions. Cases requiring probe locations of less than four to six diameters downstream from bends or obstructions, or when sampling in non-circular ducts, are likely to require samples from multiple cross-sectional regions, greatly complicating the sampling task. Local velocities can be measured across the duct to establish the velocity profile in support of isokinetic sampling. It is important to recognize that the particle size distribution of the upstream particles can be skewed from the velocity profile, depending on duct geometry and upstream and downstream obstructions. In addition, isokinetic sampling does not guarantee that there are no particle losses between the nozzle entrance and the particle counter.

Failure to sample isokinetically, termed anisokinetic sampling, is likely to cause distortions in both particle size distribution and particle concentration. This is caused by particle inertia along the curved streamlines, as the flow converges or diverges at the nozzle inlet, as illustrated in Figures I.1 b) and I.1 c) for super- and sub-isokinetic sampling, respectively. The extent of the errors in concentration for given particle sizes depends on the square root of the Stokes number, which is directly proportional to particle size and depends on the actual sampling conditions.

As shown in Figure I.1 b), the suction area in the case of super-isokinetic sampling (when the velocity entering the probe exceeds the stream velocity) is greater than for isokinetic sampling. In this case, larger particles with high inertia from this area cannot follow the converging streamlines and will be lost from the sample, while an excessive number of finer particles will follow the streamlines and enter the nozzle. This will lead to an overrepresentation of fine particles in the aerosol sample.

For sub-isokinetic sampling [Figure I.1 c),with probe velocity less than stream velocity], the suction area is smaller than for isokinetic sampling. In this case, larger particles from outside of the original sampling area will enter the nozzle, while some of the finer particles originally in the sampling area will follow the streamlines and diverge past the nozzle. This will lead to an overrepresentation of larger particles in the aerosol sample.

Isoaxial and isokinetic sampling is the ideal sampling configuration and will aspirate all representative particle sizes with nearly 100 % efficiency, especially for particles in the submicron to 10 µm range. A departure from this ideal configuration into regions of anisokinetic and anisoaxial sampling results in non-representative sampling. This should be avoided when making fractional efficiency measurements.

Because particle counters have fixed flow rates, isokinetic sampling is achieved by changing the size of the sampling probe inlet to provide velocity matching. This is accomplished using Equation (I.1), assuming the probe inlet and approach velocities are equal and that probe and duct airflow rates are known. For this case, the probe inside diameter, d, would normally be equal to the main duct diameter, D, multiplied by the square root of the ratio of the sampler flow rate, q, to the main duct flow rate, Q, as shown in Equation (I.1):

$$d = D\sqrt{\left(\frac{q}{Q}\right)} \tag{I.1}$$

It has been shown, however, that more accurate results are obtained when using Equation (I.2) to determine inside probe diameter:

$$d = \sqrt{\frac{Q\left(D^2 - d_\mathrm{o}{}^2\right)}{q}} \tag{I.2}$$

where

Q is the flow rate in test duct;

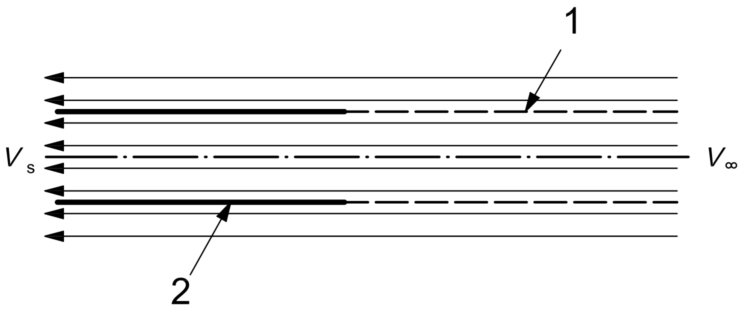
D is the diameter of test duct;

d_o is the outside diameter of sampling probe;

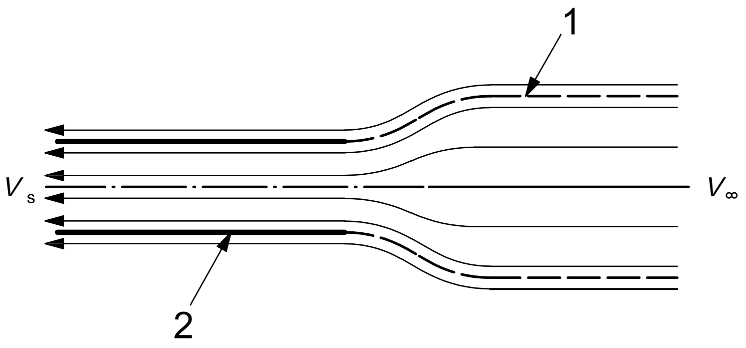
q is the flow rate in sample line.

Acceptable sampling nozzle designs are shown in Figure I.2.

As noted, anisoaxial sampling causes particles with sufficient inertia to diverge from the aerosol streamlines resulting in lower sampling efficiencies that can significantly deviate from 100 %. Thus, anisoaxial sampling will almost always underestimate particle concentration. However, for misalignments up to 15°, the error in concentration is small for all particle sizes. Because misalignment is visually obvious, eye positioning of the sample probe is adequate when the direction of the streamlines is well known.

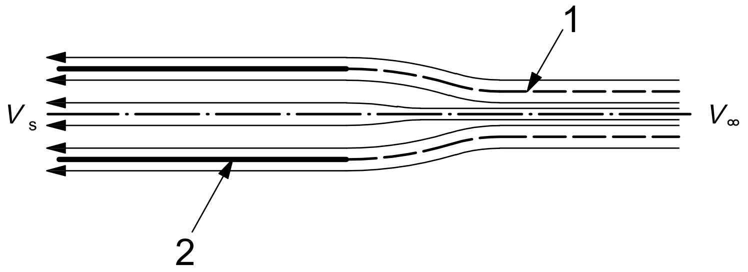


a) Isokinetic sampling, $V_\mathrm{s} = V_\infty$



b) Super-isokinetic sampling, $V_\mathrm{s} > V_\infty$

Figure I.1 — Types of sampling nozzles (*continued*)



c) **Sub-isokinetic sampling, $V_s < V_\infty$**

Key

1	limiting streamline
2	sampling nozzle
V_∞	air velocity entering the probe
V_s	free stream velocity approaching the inlet

Figure I.1 — Types of aerosol isokinetic sampling

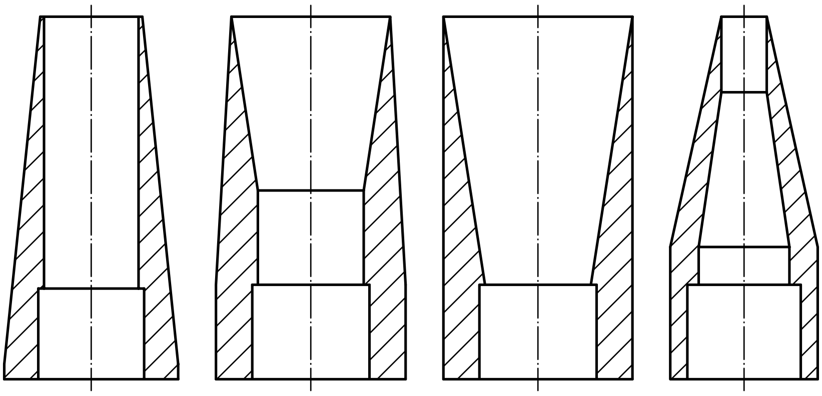


Figure I.2 — Types of sampling nozzles

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